DOCTOR OF PHILOSOPHY

An eye-movement analysis of the word-predictability effect

Paul, Shirley-Anne, S.

Award date:
2010

An eye-movement analysis of the word-predictability effect

Shirley-Anne, S. Paul

2010

University of Dundee

UNIVERSITY OF DUNDEE

An Eye-Movement Analysis of the Word-Predictability Effect

By

Shirley-Anne Stuart Paul MA (Hons) MSc

Submitted for the degree of Doctoral of Philosophy

21/10/2010

School of Psychology

Faculty of Arts and Social Sciences

University of Dundee

Declaration

I hereby declare that this thesis has not been submitted either in the same or different form, to this or any other University for a degree.

Shirley-Anne Paul. Signature: Shirley Paul Date: 21/10/10

Certificate

I certify that Shirley-Anne Paul has spent the equivalent of at least nine terms on research work under my supervision and that she has fulfilled the conditions of Ordinance No 39 so that she is qualified to submit this thesis for the degree of Doctor of Philosophy.

Dr. Wayne S. Murray. Signature: Wayne Murray Date: 21/10/10

Acknowledgements

I would like to thank my family and friends who have supported me throughout my time in University. In particular, I would like to thank my mother, who has always believed in my abilities and encouraged me to strive towards my goals. My brother is also a firm supporter of my work and I must have sufficiently inspired him as he now follows in my footsteps (good luck Graeme!). I would also like to thank my grandmother and grandfather. My grandfather has been there for me every step of the way, and hopefully, one day I will be as wise as he is.

I owe special thanks to both my “academic fathers”, Alan and Wayne, for their intellectual support and for giving me the motivation I needed to complete this thesis. In fact, without their encouragement, I would not have contemplated embarking upon a PhD. To them, I am eternally grateful.

Of course I would not have been able to undertake this PhD if it were not for the financial support I received from the Economic and Social Research Council which funded both my Masters degree and the PhD, and who now continue to fund my research. Thus, to them, I am also extremely grateful.

A big thank you goes to James Robertson for putting up with me over the last few months and for making me all those dinners so that I could keep on working. I would also like to thank my very good friends who, throughout this process, have provided me with much needed “fun time”: Adele Maxwell, Claire Deas, Louise Heggie, Emma Christie, Arlie McLeary, Julie Phimister, Maria Reekie, Laura Wakeford & Kelly Christie.

Since it is customary in our family to sign our cats' names in birthday cards etc., I must acknowledge Kerry, Sophie and Charlie (and also Basil) who kept me company whilst I was writing-up.

Abstract

The primary aim of this thesis was to identify the mechanism under-pinning the word-predictability effect, while a secondary aim was to investigate whether words are processed in serial or in parallel. In five experiments, adults' eye-movements were monitored as they read sentences for comprehension on a computer screen. In Experiments 1 and 2, a critical target-word that was either of high- or low-frequency and either predictable or unpredictable was embedded in experimental sentences. The nature of the preview of the target word was also manipulated such that it was either identical to the target or was misspelled (the misspelling was more severe in Experiment 2). Predictability effects were apparent in the identical preview condition in both experiments, whilst they were only apparent in the misspelled condition of Experiment 1. This outcome is compatible with early Guessing Game type models of reading which propose that readers make predictions about up-coming words using contextual and parafoveal information. When taken together, the results of Experiments 1 and 2 also suggested that frequency and predictability exert additive effects on fixation durations.

In Experiment 3, four levels of word-predictability were employed. The function relating word-predictability and word-processing time was strictly monotonic: word-processing time decreased as predictability increased. This outcome was consistent with a word-prediction account of predictability in which there is no penalty for incorrect guessing. Experiment 3 also showed that processing time on the pre-target word increased as the predictability of the up-coming target increased. This outcome replicated an effect obtained by Kliegl, Nuthmann and Engbert (2006) who claim that it arises as a result of memory retrieval processes cued by prior sentence context.

Experiment 4 replicated the manipulation in Experiment 3 but included an additional condition in which the preview of the target word was masked while in parafoveal vision, using a pixel scrambling technique. The target-predictability effect was again a graded one, and did not depend upon the availability of initial parafoveal information, providing evidence against the word-prediction theory. Additionally, there was no pre-target predictability effect in the unmasked condition. There was a pre-target effect in an orthodox direction in the masked condition, although this appeared to be a consequence of the mask. Experiment 5 replicated Experiment 4, but replaced the masked condition with a non-predictable but semantically related word, and the results showed no pre-target effects at all. It was concluded that inverted pre-target predictability effects are more likely to be related to higher-level sentential processing.

In Experiment 5, the target words were also replaced with non-predictable but semantically related words. Effects of context, similar in form to those obtained in Experiments 3 and 4 were obtained on the target word, an outcome compatible with the hypothesis that predictability effects are the result of post-lexical semantic integration, as opposed to a contextual facilitation of lexical access. Overall, the data are consistent with a modular theory of language processing, while there was no evidence against serial processing during reading.

Table of Contents

List of Tables

List of Figures

Chapter 1:

Theories of eye-movement control during reading

1.1. Overview of thesis

This thesis is concerned with investigating the effects of cognitive variables that are thought to influence the lexical access of words. By utilising the eye-tracking methodology, the effects of word-frequency and word-predictability are explored, with emphasis on the latter. Word frequency is a term used to refer to how often a word is used in written language and in the reading literature, a distinction is made between high- and low-frequency words. A high-frequency word for example, is ‘the’ which is the most frequently used word in the English language, whereas a low-frequency word is ‘armadillo’ which is rarely used. Word-predictability, which is highly correlated with word-frequency, refers to how predictable a particular word is in a sentence given the nature of the preceding sentence context. Thus, if the context of a sentence is highly constrained towards ‘cat’, then ‘cat’ can be said to be predictable, whereas if the context is not constrained towards ‘cat’ then ‘cat’ can be defined as unpredictable.

The nature and effects of word-frequency are fairly well-understood but the nature and temporal locus of word- predictability effects are relatively still unknown. That is, it is has been shown many times that predictable words are processed faster than unpredictable words (e.g. Rayner, Ashby, Pollatsek & Reichle, 2004; Binder, Pollatsek & Rayner, 1999; Altarriba, Kroll, Sholl & Rayner, 1996; Frisson, Rayner & Pickering, 2005; Lavigne, Vitu & d’Ydewalle, 2000; Rayner & Well, 1996; Balota, Pollatsek & Rayner, 1985; Calvo & Meseguer, 2002; Ehrlich & Rayner, 1981; Inhoff,

1984) but it is not yet clear why this effect arises. Somewhat surprisingly, researchers have primarily concerned themselves with recording and modelling the effects of word predictability rather than investigating how predictability actually operates. Given that the effect must be at least partly driven by the nature of the sentential context in which words are embedded, suggests that high-level factors operating at the sentence-level contribute towards the effect, however, the nature of these is still unapparent. For example, the effect could be driven by anticipatory or syntactic processes, or it could be the result of a process of semantic integration. If it is the latter, then it may be integration of the critical word to the global meaning of the sentence which drives the effect or it could be the local context surrounding the critical word which is of importance. The predictability effect may also be partly driven by processes operating at the level of the word. For example, the nature of the information initially available in parafoveal vision may either facilitate or inhibit the predictability effect. Whether this is the case, bears on the issue of whether predictability exerts its effect at the level of lexical access. Thus, the predictability effect could potentially be driven by a number of factors and this thesis sets out to identify some of those factors. Further aims of the thesis are to determine the nature of the functional relationship between word-predictability and word-processing time, since this can also help to reveal the nature of the effect, and to determine whether word-frequency and word-predictability exert interactive or additive effects on word-identification time. Resolution of this latter issue can provide insight into the time-frame of the predictability (and the word-frequency) effect. This thesis also addresses a separate on-going debate in the literature regarding whether during reading, words are processed in serial or in parallel.

The nature of predictability effects and the outcome of the issues outlined above could have critical consequences for models of eye-movement control which try to account for frequency and predictability effects and other phenomena known to influence eye movements during reading. The starting point of this thesis is therefore to begin by giving a short historical account of theories of eye-movement control during reading before giving an in-depth description and discussion of the *E-Z Reader* model (Reichle, Pollatsek, Fisher and Rayner, 1998; Reichle, Rayner & Pollatsek, 2003; Rayner, Reichle and Pollatsek, 2005; Reichle, Pollatsek & Rayner, 2006; Pollatsek, Reichle & Rayner, 2006c; Reichle, McConnell & Warren, 2009) and the SWIFT model (Engbert, Longtin & Kliegl, 2002; Kliegl & Engbert, 2003; Engbert, Nuthmann, Richter & Kliegl, 2005; Richter, Engbert & Kliegl, 2006). These models are discussed because to date, they are the most fully-developed and as a consequence, are currently the most influential models of eye-movement control during reading. Both models seek to explain frequency and predictability effects but have different architectures, meaning that some of the predictions relating to the effects of frequency and predictability differ. In addition, the *E-Z Reader* and SWIFT models offer contrasting accounts regarding whether lexical processing is distributed or occurs in a serial-sequential manner. Thus it is crucial to discuss the architectures and mechanisms implemented in these models before considering the experimental research which has been conducted previously (see Chapter 2) and the research carried out for this thesis (Chapters 4- 8) which help to discriminate between the two models.

1.2. Theories of eye-movement control during reading

Over the past thirty years, many models have been advanced which try to account for how eye movements are controlled during reading. A good model must be able to account for the two most important aspects of eye movement behaviour during reading: 1. Where to fixate next (the *where*? decision/spatial aspect) and 2. When to move the eyes (the *when*? decision/temporal aspect). Two main types of model have been put forth in the literature which attempt to account for this behaviour: Oculomotor models and processing models. These two models exist because there are two distinct views on what influences eye movements during reading. One viewpoint, which is inherent in oculomotor models, is that eye movement control is primarily determined by low-level oculomotor factors and that cognitive and attentional processes only indirectly influence eye movement behaviour. An extreme form of this view is that during reading, attention does not influence eye movement behaviour at all (e.g. Findlay & Walker, 1999).

Oculomotor models focus primarily on the spatial aspect of eye movement behaviour. The location in a word at which the eyes initially fixate is dependent on low-level visual processing and oculomotor factors, for example the optimal viewing position of a word (O'Regan, 1992), and mostly determines how long the eyes remain fixated. Therefore in this type of model the *when*? decision depends on the previous *where*? decision. Oculomotor models include O'Regan's (1990; 1992; O'Regan & Lévy-Schoen, 1987) strategy-tactics model, although work by Kowler and Anton (1987) and McConkie, Kerr, Reddix, Zola and Jacobs (1989; McConkie, Kerr, Reddix & Zola, 1988) can also be seen in this tradition. Some recent oculomotor models, for example the Competition-interaction model by Yang and McConkie (2001; 2004), suggest that word identification plays a minor role in controlling eye movements. The Competition-interaction model, applies the assumptions of the Push-Pull theory of saccade generation by Findlay and Walker (1999) to the reading domain. In the model, saccades are randomly executed as a result of competitive “push-pull” operations that occur among components of the oculomotor system. These “push-pull” operations are needed in order to resolve the conflict of whether to keep the eyes stationery or move them onward. In this model there is therefore little cognitive influence on *when* and *where* the eyes move (although in the model, saccades can be delayed if processing is difficult). Another recent model to grow out of the oculomotor tradition includes the Glenmore model (Reilly & Radach, 2003) which also stems from the work of Findlay and Walker (1999) since it includes a saccade generator which initiates and executes eye movements (and therefore determines *when*). In the Glenmore model, word recognition plays a greater role in controlling eye movements than in the Competition-interaction model since it includes a saliency map that selects saccade targets (thus determining *where*) and an interactive-activation network for identifying words (which also controls *where* and *when*). This model radically differs from processing models which assume that attention is allocated in a strict serial-sequential fashion because as well as assuming that lexical processing is distributed, it replaces the whole concept of attention with a salience map.

One of the most influential models of eye-movement control of the moment, the SWIFT model (Engbert, et al., 2002; Kliegl & Engbert, 2003; Engbert, et al., 2005; Richter, et al., 2006), incorporates a lot of the ideas of the Push-Pull theory and therefore has essentially grown out of the oculomotor tradition. However, in the SWIFT model, word identification plays a much greater role than in other oculomotor models and is therefore able to account for more of the cognitive influences on eye-movements than other oculomotor models can (a full description and evaluation of this model against data reported in the literature is given in section *1.5)*.

The opinion inherent in oculomotor models arose due to scepticism regarding whether cognitive processes can influence eye movements during silent reading given the time restraints involved. Fixation durations in silent reading are usually in the region of 200-250ms, with word-identification time taking approximately 150ms (Pollatsek et al., 2006c) and eye movements taking around 150-175ms to program (Rayner, Slowiaczek, Clifton & Bertera, 1983), thus suggesting that there is not much time for cognitive variables to exert an on-line influence. However, a large number of studies have shown that a wide-range of cognitive variables can and do influence fixation durations during reading. Thus the opposing viewpoint to that intrinsic in oculomotor models is that on-going attentional and cognitive processes primarily control eye movement behaviour and this is reflected in processing models of reading. Processing models mainly focus on the temporal aspect of eye movement behaviour. *When* the eyes will move is primarily determined by linguistic variables (high-level factors). *Where* the eyes will move next is mostly determined by low-level factors (e.g. word length). The main characterizing feature of the processing model is that attentional shifts and lexical processing occur in a strict serial-sequential fashion. Processing models include the highly influential model by Morrison (1984), as well as those by Just and Carpenter (1980), Rayner and McConkie (1976) and various modifications to Morrison's (1984) model (e.g. Henderson & Ferreira, 1990; Pollatsek & Rayner, 1990). More recently, Morrison's (1984) model has been modified by Reichle, et al. (1998; Reichle, et al., 2003; Rayner, et al., 2005; Reichle, et al., 2006; Pollatsek, et al., 2006c, Reichle, et al., 2009) in the form of the *E-Z Reader*, which is probably the most influential model of eye movement control in reading at the moment. The *E-Z Reader* model was developed in order to account for some of the short-comings of the Morrison model, thus it is worthwhile outlining the main features and parameters of Morrison's (1984) model as well as discussing the phenomena that this model can and cannot account for, before going on to discuss the *E-Z Reader* model.

1.3. Morrison's model of eye-movement control during reading

Morrison's (1984) model of eye-movement control during reading, proposes that each fixation begins with visual attention focused on the word currently in foveal vision (*n*). After processing of the foveal word has reached a criterion level (possibly lexical access), attention shifts to the right, to the parafoveal word (*n* + 1). This shift of attention enables processing of the word at the newly attended location to begin and signals the eye-movement system to prepare a program to move the eyes. The motor program is then executed and the eyes follow attention to the new word. The model can account for the fact that fixation time on a word is a function of the word's frequency and length. This is because word-processing will reach a criterion level faster for high-frequency words and for short words. Morrison's model can also account for the fact that many words are skipped during the reading process. This is because Morrison proposed that eye-movements can be programmed in parallel: If lexical processing of word *n* +1 is completed before the eye-movement to word *n* + 1 is executed, then attention moves ahead to word *n* + 2, and an eye-movement is programmed to word *n* + 2 (in parallel with the program to word *n* + 1). However, if lexical access of word *n* + 1 is rapid (as will be the case for high-frequency and short words), then the time between the initiation of the program to fixated word *n* + 1 and the initiation of the program to fixated word *n* + 2 will be short, meaning that the program to fixate word $n + 1$ will be cancelled and the eyes will move directly to word $n + 2$. It should be noted here that the model cannot account for the fact that predictable words are more likely to be skipped than unpredictable words (e.g. Drieghe, Brysbaert, Desmet & De Baecke, 2004; Rayner et al., 2004; Binder et al., 1999; Rayner & Well, 1996; Altarriba et al., 1996; Schustack, Ehrlich & Rayner, 1987; Balota et al., 1985; Ehrlich & Rayner, 1981) or that word recognition time is influenced by word-predictability since the model does not incorporate word-predictability. However, this is understandable given that word-predictability effects were a fairly new phenomenon when the Morrison model was conceived.

In Morrison's (1984) model, visual attention moves ahead of overt inspection, and this has a number of important implications. First, it implies that there is a dissociation between 'looking' and 'seeing' in reading. Evidence for this dissociation comes from reading studies employing the moving window paradigm which show that visual attention is allocated to the region of the visual field towards which the eyes are moving (e.g. Inhoff, Pollatsek, Posner & Rayner, 1989). The dissociation of attention and eye movements means that the model can successfully account for the fact that a reader can begin processing the next word before actually looking at it, thus accounting for parafoveal preview advantage (Rayner, 1998; Rayner & Pollatsek, 1989). However, in the model, pre-processing of a word only takes place during the time needed to prepare and execute a saccade towards it, i.e. once processing of the foveal word has been completed, thus leading to the prediction that preview advantage should be independent of foveal load. This aspect of the theory has proved difficult to sustain with data showing that preview advantage actually varies as a function of foveal load (Henderson & Ferreira, 1990). In Henderson and Ferreira's classic experiment, they simultaneously manipulated the frequency of a word in foveal vision and the preview of a word in parafoveal vision (the preview was either the same as the as-yet-unfixated parafoveal word, or visually similar or visually dissimilar to the parafoveal word). Readers' eye movements were then tracked as they read sentences into which the manipulated foveal and parafoveal words were embedded. The contingent boundary procedure was also employed so that when the eyes crossed an invisible boundary (between the foveal and parafoveal word), the parafoveal preview changed to its correct form. The authors found that first fixation durations on the parafoveal target (when it was eventually fixated) were 10ms shorter when the preview had been the same or similar while in parafoveal vision than when it had been dissimilar. That is, a preview benefit of 10ms was obtained in the same and similar preview conditions. Crucially however, this benefit was only obtained when the foveal word was of high-frequency, indicating that the preview benefit was dependent on the difficulty of the foveal word. By incorporating a saccadic deadline into Morrison's (1984) model so that eye-movement programming begins prior to the attentional shift, Henderson and Ferreira (1990) tried to account for this "foveal-on-parafoveal" influence. The operation of such a fixed deadline successfully predicts a reduction in preview advantage with increasing foveal inspection time, but also predicts an increase in intra-word re-fixations. This is because, a fixed deadline will be passed more often when foveal load is high, and if the deadline has passed before lexical access of the up-coming word takes place, then a saccade will be made to the current focus of attention which will be the word already attended to (since lexical access of the up-coming word will have not yet taken place). However, Schroyens, Vitu, Brysbaert & d'Ydewalle (1999) have found no evidence for an increase in intra-word re-fixations following such a saccadic deadline.

Two further points regarding Morrison's (1984) model also need to be made. First, the "leave-on-completion" aspect of the model means that the model cannot account for the fact that words are sometimes refixated or that sometimes there is a "spill-over" effect on word *n* + 1 arising from the difficulty of word *n*. The model's inability to account for spill-over effects is because it cannot account for foveal-on-parafoveal effects. Indeed, spill-over effects and foveal-on-parafoveal effects are in fact the same phenomenon. As discussed above, Henderson and Ferreira (1990) showed that *n* + 1 will be processed more quickly following an easy (e.g. high-frequency) word than following a difficult (e.g. low-frequency) word. This effect can be defined as either a foveal-on-parafoveal effect or a spill-over effect on word *n* + 1 emanating from the difficulty of word *n*. The failure to account for spill-over effects (or foveal-on-parafoveal effects) was actually somewhat of an embarrassment to the model, particularly since spill-over effects were initially attributed to post-lexical integration processes (e.g. Rayner & Pollatsek, 1989). The second and final point regarding Morrison's model is that since parafoveal information only becomes available when attention has shifted from the locus of foveal processing, the model predicts that parafoveal information cannot have any immediate effect on foveal processing.

1.4. The E-Z Reader Model

1.4.1. Background to the model

Reichle et al. (1998) have proposed a model of eye-movement control in reading which is an elaboration of Morrison's (1984) model. Reichle et al. set out with the aim of accounting for some of the short-comings of Morrison's model, for example, its inability to account for foveal-on-parafoveal effects and spill-over effects. In their

1998 paper, Reichle et al. present a core version of the *E-Z Reader* model (*E-Z Reader* 1) which offers an account of how eye movements in reading are driven. Four subsequent versions of *E-Z Reader* were proposed in the original 1998 paper and a further five versions have since been put forward, all with the aims of accounting for more of the factors that are known to influence eye-movements during reading and improving the fit of the model to eye-movement data. The latest edition of the model is the *E-Z Reader* 10 (Reichle et al., 2009) and this version will be described before an in-depth discussion of what phenomena the model can and cannot account for, is undertaken. For the sake of simplicity, *E-Z Reader* 10 will from here forth be referred to as *E-Z Reader* while all previous versions referred to will be specified, e.g. *E-Z Reader* 9, etc.

Before the *E-Z Reader* model is discussed it should be noted that the fixation durations predicted by the model were obtained by simulating data collected by Schilling, Rayner and Chumbley (1998) in an eye-tracking experiment aimed at examining the effects of word-frequency in reading, lexical decision and pronunciation tasks. In the experiment, participants were presented with 48 sentences and the frequency, probability of skipping, first fixation, single fixation and gaze duration for each word in the sentences was calculated. The words from the Schilling et al. data were then separated into five different frequency classes (1-10, 11-100, 101-1000, 1001-10,000 and 10,001 + counts per million) so that there was a data-set for each of the five classes. Reichle et al. (1998) determined the predictability of the words (which were from the Schilling et al., data-set) used in simulations of the *E-Z Reader* model by conducting a norming experiment. In the experiment, 20 participants were presented with each sentence word by word, and after the presentation of each word, they were instructed to guess the next word in the sentence.

1.4.2. E-Z Reader 10

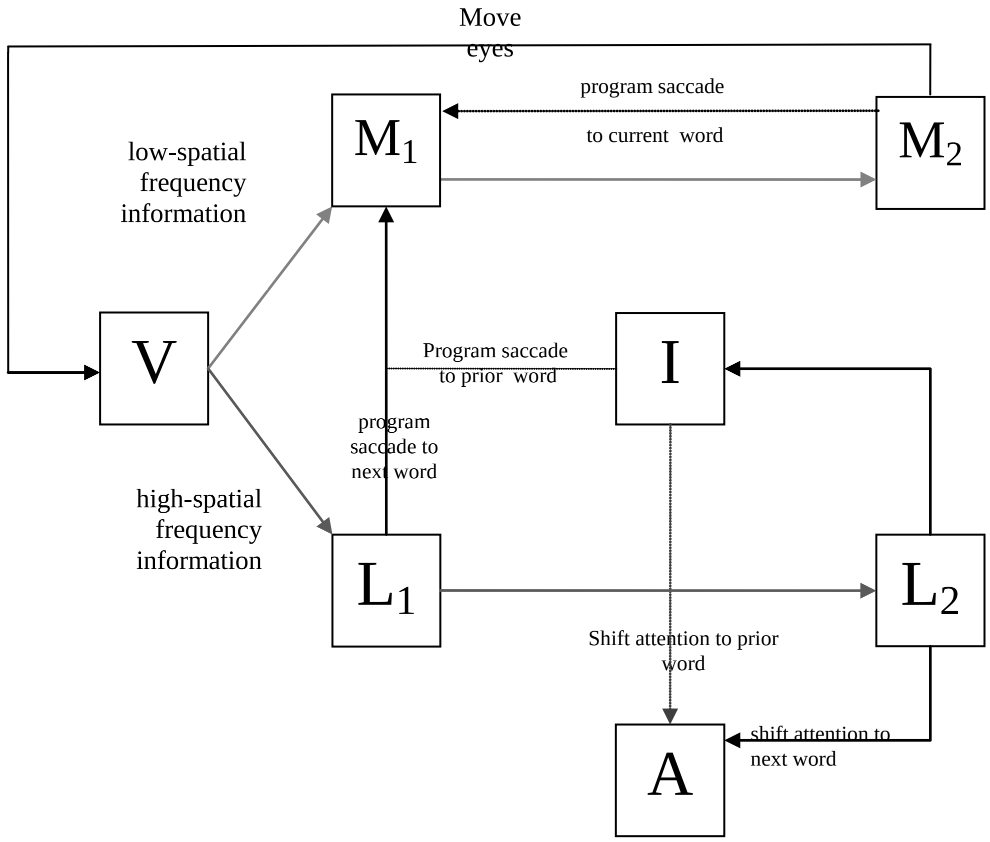


Figure 1.1. A schematic diagram of *E-Z Reader* 10. Adapted from Reichle et al. (2009).

The fundamental assumption of the *E-Z Reader* model is that the eyes are driven forward by the lexical properties of individual words. According to *E-Z Reader*, this process begins with early visual processing of a word via a ‘visual system’. During this early visual processing, low-spatial-frequency visual information (such as word-boundary information) is transmitted to the brain. This process is presumed to take 50ms to complete based on research (e.g. Clark, Fan & Hillyard, 1995; Foxe & Simpson, 2002; Mouchetant-Rostaing, Giard, Bentin, Aguera & Pernier, 2000; Van

Rullen & Thorpe, 2001) which has shown that information to the retina is not transmitted instantaneously to the brain but lags behind by around 45-55ms. Thus, this aspect of the model (as well as other aspects discussed below) presupposes that information comes in packets or in stages[1].

Following early visual processing, the process of word-identification begins. In *E-Z Reader*, word-identification is a two-stage process and this is what fundamentally differentiates the model from the Morrison (1984) model. In the *E-Z Reader* model, the first stage of word-identification involves a 'familiarity check' of the word and equals 0.7 of word-identification time. This process takes into account many factors, such as the length, frequency and predictability of a word. However, the authors have never clearly defined the exact nature of this process (the issue seems to be whether word-identification involves more than just a crude check of the word's orthographical and frequency status or not) resulting in the familiarity check term being used interchangeably with the term L_1 (i.e. the first stage of lexical processing). The second stage is where lexical access takes place and this is achieved when a word's orthographic or phonological pattern is identified and information about a word's meaning is retrieved. This stage is assumed to equal 0.3[2] of word-identification time and has been used interchangeably with the term L_2. [3]

Both L_1 and L_2 are a linear function of the log frequency and the log predictability of a word. This aspect of the model seems somewhat limited since it is likely that other cognitive variables (such as word-neighbourhood frequency) influence word-

---

[1] Spivey (2007) argues against the notion of stages and instead argues that disparate information sources are continuously integrated.
[2] The authors are vague about why L_1 and L_2 are predicted to equal 0.7 and 0.3 of word-identification time respectively.
[3] For the sake of simplicity, when referring to the stages of lexical access within the *E-Z Reader*, the terms L_1 and L_2 will be employed respectively.

identification. Furthermore, Huestegge, Grainger and Radach, 2003, rightly point out that the relationship between frequency and predictability with the orthographic, phonological and semantic processing described in the verbal model is not specified. Nevertheless, while the frequency of a word fully affects the time to complete L_1, predictability only partially affects L_1 time but fully affects the time to complete L_2. In the model, decreasing visual acuity also attenuates the rate at which L_1 completes: The duration of L_1 increases as the length of word *n* increases and as the distance of the centre of word *n* from the fovea increases. This parameter allows the model to account for word-length effects (e.g. Just & Carpenter, 1980) and the optimal viewing position effect respectively.

Following the completion of L_2, a post-lexical integration stage begins. This stage takes 50ms and is assumed to reflect post-lexical integration processes such as linking the meaning of a word into a syntactic structure. The post-lexical integration stage is followed by a labile stage (which is subject to cancellation by subsequent programs) and then a non-labile stage (which cannot be cancelled by subsequent programs) of saccade programming which is then followed by a saccadic eye movement to the next word. The labile stage of saccadic programming is specified as consisting of two sub-stages: A general system preparation stage and a location-to-distance transformation stage in which the spatial location of the up-coming saccade target is converted into saccade length. The mean minimal time to complete the labile and non-labile stages are defined as being 100ms and 25ms respectively, while saccade durations are presumed to be of 25ms (similar saccade latencies have been shown in saccade latency tasks, e.g. Becker & Jurgens, 1979).

A fundamental aspect of the model is that covert attention shifts and the program to make an eye-movement are decoupled: Completion of L_1 is the signal for the initiation of an eye-movement program while completion of L_2 is the signal for a shift of covert attention (the shift of attention is assumed to take 20ms). Since covert attention moves ahead while foveal processing is still being carried out (i.e. the eyes have not moved on to the next word yet), this means that *E-Z Reader* can account for preview benefit. This aspect of the model can also account for effects of foveal load on preview advantage and/or spill-over effects (an in-depth description of how the model accounts for these effects is given later) and is therefore what fundamentally differentiates this model from the Morrison (1984) model.

1.4.3. How the model accounts for frequency and predictability effects

Since both stages of the word-identification process are a linear function of the log frequency and the log predictability of a word, this means that these stages are completed faster when 1. The word is of high-frequency than when it is of low-frequency and 2. The word is predictable than when it is unpredictable. The inclusion of this parameter is crucial to the validity of the model given the fact that high-frequency words are processed faster than low-frequency words (e.g. Altarriba, et al., 1996; Henderson & Ferreira, 1990;1993; Hyönä & Olson, 1995; Inhoff & Rayner, 1986; Just & Carpenter, 1980; Kennison & Clifton, 1995; Raney & Rayner, 1995; Rayner, 1977; Rayner & Duffy, 1986; Rayner & Fischer, 1996; Rayner & Raney, 1996; Rayner, Sereno & Raney, 1996; Rayner, Fischer & Pollatsek, 1998; Vitu, 1991) and that predictable words are processed faster than are unpredictable words (e.g. Rayner, et al., 2004; Binder, et al., 1999; Altarriba, et al., 1996; Frisson, et al., 2005; Lavigne, et al., 2000; Rayner & Well, 1996; Balota, et al., 1985; Calvo & Meseguer, 2002; Ehrlich & Rayner, 1981; Inhoff, 1984). The authors also account for predictability effects by suggesting that if a word can be correctly predicted given the preceding sentence context then the completion of the L_1 stage is not necessary and the reader will instead use the top-down information available about the word from its context to immediately begin L_2 (this mechanism also accounts for why predictable words are skipped). This means that L_1 will be equal to zero for very predictable words but will be a value greater that zero for less predictable words.

As previously discussed, predictability only partially affects L_1 time but fully affects L_2 time, meaning that in the model, predictability exerts a greater effect on the later stages of lexical access. However, this aspect of the model is actually implausible given that predictability has been shown to affect first fixation durations (e.g. Rayner, et al., 2004; Binder, et al., 1999; Altarriba, et al., 1996), a very ‘early’ measure usually associated with lexical access (see Chapter 3 for discussion of early and late reading measures). A study by Sparrow, Miellet and Coello (2003) also casts doubt on whether the greatest effects of predictability should be restricted to later stages of lexical access. Sparrow et al. carried out an eye-tracking experiment in which fifteen participants read a French text that consisted of 134 words varying in frequency and predictability. In order to determine how well *E-Z Reader* 7 could predict the magnitude of the predictability effects obtained in their experiment, the authors ran a simulation of *E-Z Reader* 7 using the data obtained in their experiment. Although predictability effects were in the usual direction (e.g. shorter fixations for high-predictable words), Sparrow et al. showed that the E-Z Reader 7 under-estimated the magnitude of the effects obtained in their data-set. Specifically, for first fixation durations, a 19ms effect was obtained by Sparrow et al. and a 4ms effect was predicted by the model, while for single fixation durations, the effects were 20ms and

3ms respectively. Since first fixation durations and single fixation durations are both early reading measures, Sparrow et al.'s results suggests that predictability may have more of an effect during the initial stage (i.e. L_1) of lexical processing than *E-Z Reader* proposes.

1.4.4. Does the model predict additive or interactive effects of frequency and predictability?

An early version of the model (version 2c, Reichle et al., 1998) assumed that the relationship between word-frequency and word-predictability on word-processing time is multiplicative. However, this assumption was changed in *E-Z Reader* 8 (Rayner et al., 2005) to account for the findings of a spate of eye-tracking studies (e.g. Rayner et al., 2004; Altarriba et al., 1996; Lavigne et al., 2000; Rayner et al., 2001; Ashby et al., 2005) which suggest that the two variables exert additive effects on fixation durations. Thus, frequency and predictability are now combined additively in the model. It may be the case however, that the authors of *E-Z Reader* were rather hasty in changing a parameter of their model since a recent study by Hand, Miellet, O'Donnell and Sereno (2006) suggests that the two variables interact when launch position into the up-coming word is controlled. The studies which address this issue and the theoretical importance of the issue will be discussed in-depth in Chapter 2.

1.4.5. How the model accounts for word-skipping effects

It has been suggested that approximately 30 per cent of the words in text are skipped during reading (Rayner, 1998) so any serious model of eye-movement control must be able to explain word-skipping. In *E-Z Reader*, the decision to skip a word is made when the L_1 stage of the to-be-skipped word (e.g. *n + 1*) has been completed in the parafovea which occurs during the fixation of the current word (*n*). When L_1 of word *n+1* has been completed, a signal goes out telling the oculomotor system to program a saccade to the following word (*n+2*). If the signal goes out early enough during the formation of the program to fixate word *n+1* it will cancel this program so that the saccade from word *n* will be to word *n + 2* and word *n + 1* will be skipped. The model can successfully account for the fact that short words are more likely to be skipped than long words (e.g. Brysbaert & Vitu, 1998; Drieghe, et al., 2004; Rayner, 1979; Rayner & McConkie, 1976), that predictable words are more likely to be skipped than unpredictable words, and that high-frequency words are more likely to be skipped than low-frequency words (e.g. Henderson & Ferreira, 1993; Radach & Kempe, 1993; Rayner & Fischer, 1996; Rayner et al., 1996). This is because L_1 completes faster for high-frequency words, short words and predictable words, meaning that the signal to program a saccade to word *n + 2* will go out early and the program to execute a saccade to word *n+1* will be more likely to be cancelled. The model cannot readily explain the finding that function words are more likely to be skipped than content words (e.g. Carpenter & Just, 1983; Rayner & Duffy, 1986; Kliegl, Risse & Laubrock, 2007) since 'word-function' is not incorporated into the model. However, this is not necessarily a great weakness as function words are typically shorter, of higher frequency and are more predictable than content words.

Since the word-skipping parameter involves the program to move the eyes to word *n + 1* being cancelled and replaced by a program to move the eyes to word *n + 2*, a necessary consequence is that when readers skip a word, the fixation duration on the word preceding the skip (*n*) should be longer than in cases where the up-coming word is not skipped. This inflated fixation duration has been found in several studies (e.g.

Pollatsek, Rayner & Balota, 1986; Hogaboam, 1983; Drieghe, Rayner, & Pollatsek., 2005; Pynte, Kennedy & Ducrot, 2004; Rayner et al., 2004), however it has not been found in others (Drieghe, et al., 2004; Engbert et al., 2002; Radach & Heller, 2000). Thus, the validity of the word-skipping module in *E-Z Reader* is questionable.

1.4.6. How the model accounts for effects relating to parafoveal preview

It should be recalled that in the *E-Z Reader* model, completion of L_1 is the signal for the initiation of an eye-movement program while completion of L_2 is the signal for a shift of covert attention. This decoupling of attention and eye-movements is a fundamental mechanism in the model as it enables it to account for effects relating to parafoveal preview. Similar to Morrison's (1984) model, pre-processing of word n + 1 can take place before n + 1 is fixated. In *E-Z Reader*, pre-processing of word n + 1 begins when L_2 is completed and attention has shifted to word n + 1. This pre-processing means that less time will be needed to process n + 1 when it is eventually fixated and therefore allows the model to account for preview advantage. Rayner et al. (2005) compared the *E-Z Reader* 8 with data obtained in moving-window and boundary change experiments by simulating first fixation and gaze durations on target words when parafoveal processing of the targets was allowed and when parafoveal processing was prevented. The model predicted a preview benefit of 42ms on first fixation durations and 50ms on gaze durations, which are comparable to the mean 42ms preview benefit Hyona, Bertram and Pollatsek (2004) obtained across seven studies.

It will be recalled that in the Morrison (1984) model, pre-processing of n + 1 could only take place during the programming and execution of an eye-movement (which occurs when processing of the foveal word is complete), meaning that the model could not account for the effect of foveal difficulty on the processing of *n* + 1. In the *E-Z Reader* model, the programming of a saccade begins earlier (following completion of L_1) although as discussed above, pre-processing is still only predicted to occur after foveal processing is complete (i.e. after completion of L_2). However, and critically, since L_1 takes longer to complete for more difficult (e.g. low-frequency and/or unpredictable) words, the completion of L_2 will subsequently be delayed in these cases and there will be less time for pre-processing of *n* + 1 following completion of L_2 (this latter point is true since in the model, pre-processing time is limited to the duration of the interval between the completion of L_2 and the execution of the saccade). Thus, the model successfully predicts that more time will be spent processing *n* + 1 when word *n* is difficult and this effect is attributed to the fact that less pre-processing of *n* + 1 can take place when *n* is difficult. However, the ability to account for this foveal-on-parafoveal influence obviously depends upon the notion of a two-stage process of word-identification being valid, as well as the nature of the L_1 and L_2 stages, being correctly specified.

1.4.7. How the model accounts for spill-over effects

In the literature, there is a vast amount of evidence to suggest that there is an effect of the difficulty of a currently fixated word (*n*) on the fixation duration of the following word (*n* + 1). For example, fixation time on *n* + 1 can be inflated following fixation of a low-frequency word (e.g. Rayner & Duffy, 1986) or of an unpredictable word (e.g. Frisson, et al., 2005; Calvo & Meseguer, 2002; Balota, et al., 1985). Following the discussion in the previous section, by definition, spill-over effects are foveal-on-parafoveal effects. *E-Z Reader* therefore accounts for spill-over effects via the same mechanism that accounts for foveal-on-parafoveal effects: When word *n* is difficult, more time is spent processing it, meaning that less parafoveal processing of *n* + 1 takes place and as a consequence, more time will be needed to process *n* + 1 when it is eventually fixated.

1.4.8. Can the model account for where words are fixated?

With the assumption that the optimal viewing position (OVP) of a word is its centre (O'Regan, 1992), in *E-Z Reader*, the predicted location of a fixation is determined by calculating the distance between a given current fixation and the centre of an up-coming word. The model also includes a parameter which is based on the idea that during reading, there is a systematic range error that causes the eyes to either undershoot or overshoot a target (e.g. McConkie, et al., 1988). The calculation of this parameter was based on McConkie et al.'s (1988) data which showed that a range error does not occur when saccade length is 7 characters, but that there is approximately 0.5 character of an overshoot with every 1 character increase in saccade length and an 0.5 character undershoot per 1 character decrease in saccade length. These parameters were introduced in *E-Z Reader* 6 (Reichle et al., 1999) and via model simulations, predicted first fixation locations on four-, five-, six- and seven-letter words were calculated as a function of four different launch sites. Reichle et al. (1999) concluded that their predicted data was close to the observed data obtained by McConkie et al. Reichle et al. (1999) also added a further rule to account for McConkie et al.'s (1988) finding that the magnitude of the range error decreases as fixation durations on launch site increases. The theoretical issue behind this is that presumably longer fixation durations on launch sites will allow the system to more accurately locate a target. Again, model simulations showed that the predicted data were close to McConkie et al.'s data. That is, longer launch site fixations resulted in saccades landing closer to word-centres. The inclusion of these parameters may be based on an inaccurate premise however. That is, there is evidence to suggest that there is in fact no range effect in reading (e.g. Kapoula & Robinson, 1986; Vitu, 1991; Vitu, Lancelin & Marrier d'Unienville, 2007). Vitu has shown, for example, that saccadic undershoots to remote targets often occur in reading, but that systematic overshoots to near targets do not occur. Furthermore, there is also evidence of an Inverted Optimal Viewing Position (IOVP) effect during reading (Vitu, McConkie, Kerr & O'Regan, 2001) in which, and in contrast to the OVP effect, single fixation durations are longer on word-centres and shorter at the beginning and ends of words. Nuthmann, Engbert and Kliegl (2005) suggest that this IOVP effect arises due to mis-locations followed by fast corrections. Although random error due to oculomotor variability is also included in *E-Z Reader*, the model can only account for IOVP effects which are the result of more than one fixation on a word (via a re-fixation mechanism). It cannot account for single fixation IOVP effects.

Although *where* the eyes move next are primarily dependent on oculomotor factors, the model can also account for findings which imply that the initial orthography of a parafoveal word can determine where this word will be fixated (e.g. Pynte & Kennedy, 2006; White & Liversedge, 2004; Pynte et al., 2004; Radach, Inhoff & Heller, 2004; Vonk, Radach & van Rijn, 2000; Beauvillain & Doré, 1998; Doré & Beauvillain, 1997; Beauvillain, Doré & Baudouin, 1996; Hyönä, 1995a). This is because, during the early visual processing stage, low-spatial visual information from across the whole page is acquired and is processed in parallel. Word-boundary information is also obtained during the early visual processing stage (it is used by the 'oculomotor system' to select saccade targets), meaning that the model can also account for the influence of the word-length of an as-yet-unfixated word on where we fixate next (e.g. Drieghe, Brysbaert & Desmet, 2005).

1.4.9. Can the model account for re-fixations?

Any model of eye movement control must be able to account for the fact that often a number of fixations are made on a word (i.e. intra-word re-fixations) and that previous words are sometimes regressed to (i.e. inter-word re-fixations). With regard to the former, in *E-Z Reader*, both intra-word re-fixations and forward inter-word saccades (i.e. saccades to the next word) are programmed and executed by a single set of motor processes although at different times. In an earlier version of the model (*E-Z Reader* 3, Reichle et al., 1998), planning of the labile stage of intra-word saccades began as soon as a word is fixated (meaning that the default state after a saccade lands was to refixate), while the labile stage of saccadic programming to the next word began after L_1 has been completed. In *E-Z Reader* 3, completion of L_1 therefore prevented a word from being fixated too long/indefinitely and could also cancel the program to refixate a word (this mechanism is therefore the same as the one responsible for word-skipping as late programs can cancel earlier ones). However, the correct proportion of regressive intra-word saccades made for high- and low-frequency words was only predicted when the labile programming of automatic refixations completed before the first stage of lexical processing. This meant that refixation saccades occurred too quickly resulting in short initial fixation durations for low-frequency words. In *E-Z Reader* 7 (Reichle et al., 2003), the refixation rule was re-defined so that refixations are not automatic (and this is still the case in *E-Z Reader* 10). Instead, upon fixating a word, a refixation labile program is initiated with a probability that is determined by the length of the fixated word: Completion of the refixation labile program takes longer as word-length increases, resulting in the increased likelihood of a refixation being made. This means that the model can account for the fact that long words are more likely to be refixated than short words (e.g. Rayner & McConkie, 1976). The model can also account for the finding that low-frequency words are more likely to be refixated than high-frequency words (e.g. Inhoff & Rayner, 1986; Rayner, et al., 1996; McConkie et al., 1989): Since the first stage of lexical processing takes longer for low-frequency words, the refixation program is more likely to initiate in these cases.

The *E-Z Reader* model also accounts for how initial fixation location can modulate intra-word re-fixation probability. Previous research has shown that the probability of making a refixation is greatest following fixations on the beginning of the word, but decreases towards the centre of the word and increases again when the fixation is near the end of the word (e.g. Reilly & O'Regan, 1998; Rayner et al., 1996). *E-Z Reader* predicts this pattern of effects: Refixations occur when the labile program to make an intra-word saccade completes before L_1 and L_1 takes longer when the fixation is on either side of the centre of a word.

In *E-Z Reader* 10, rules were introduced so that intra-word re-fixations also arise due to both integration difficulty and oculomotor error, as a function of the mean duration of the post-lexical integration stage. With regard to the former, as integration difficulty increases, the probability of making an intra-word re-fixation increases. With regard to re-fixations which are due to oculomotor error, in the model it is proposed that these are caused by re-fixation saccades that are directed from the ends of words back towards to their centres, however, due to motor error, the saccades sometimes overshoot their targets, producing intra-word (and inter-word) re-fixations. This latter mechanism therefore allows *E-Z Reader* to account for the IOVP effect.

Up until *E-Z Reader* 9, the model could not account for any inter-word re-fixations, however a small proportion are now predicted to occur on words that have been skipped and in *E-Z Reader* 10, the likelihood of making an inter-word re-fixation also increases as the difficulty of word-integration increases. With regard to the latter, the model proposes that if L_2 completes on word $n + 1$ before post-lexical processing of word n completes, then a regression will be made back to word n so that it can be processed again. This is of course a startling claim since it involves a reversal of the direction of attention and therefore is not very plausible in a serial model. Also somewhat problematically, the model doesn't stipulate what happens after re-processing of word n has taken place. That is, word $n + 1$ could either be skipped since L_2 has already completed or it could be processed again since post-lexical processing will not have taken place yet. Despite these uncertainties, the model seems to give a plausible account for why some inter-word re-fixations occur, however, it cannot account for the fact that often long regressive saccades are made (e.g. Frazier & Rayner, 1982; Kennedy, 1983; Kennedy & Murray, 1987a; 1987b; Murray & Kennedy, 1988) and does not specify the exact location of regressive (either inter- or intra-word) saccades.

1.4.10. Does the model predict any parallel processing?

A large number of studies (see chapter 2) have shown that both 'low-level' properties (e.g. the orthography) and 'high-level' properties (e.g. the word-frequency, word-predictability and pragmatic plausibility) of a parafoveal word can influence inspection times on a currently fixated word. This phenomenon is commonly referred to in the literature as ‘parafoveal-on-foveal’ effects and implies that word-encoding takes place across a processing gradient. It will be recalled that in *E-Z Reader,* some low-level parallel processing can take place which can subsequently influence where words are first fixated. However, the model cannot readily account for effects on word *n* from high-level properties of word *n* + 1 given that the model proposes that words are processed one at a time in a serial-order (it is acknowledged that words are sometimes re-fixated, whether this can account for parafoveal-on-foveal effects will be addressed below). Reichle et al. (2003) suggest that the effects found in the afore-mentioned studies are not the result of word *n* and *n + 1* being processed in parallel but instead are the result of ‘mislocated fixations’. They suggest that unintended fixations will occur on word *n* in cases where the saccade undershoots the target *n + 1* and furthermore, since their model predicts occasional saccadic errors, the authors claim that they can actually account for a small percentage of parafoveal-on-foveal effects. However, Kennedy (2008) offers a number of arguments which show that *E-Z Reader* cannot explain parafoveal-on-foveal effects in terms of mislocated fixations. For example, parafoveal-on-foveal effects should not be evident in the measure of first fixation duration (since the mislocated fixation would be towards the end of a word), however, in the literature, there is evidence of parafoveal-on-foveal effects in first fixations. Additionally, the mislocated fixation hypothesis predicts that parafoveal-on-foveal effects should not be obtained when only one fixation is made on word *n* (Pynte & Kennedy, 2005) however, there is also evidence of parafoveal-on-foveal effects arising in the measure of single fixation duration (e.g. Kennedy & Pynte, 2005; Nuthmann, Kliegl & Engbert, 2006). These latter findings mean that it is also impossible for the model to explain parafoveal-on-foveal effects in terms of re-fixations.

A related issue to be addressed here is whether the idea that sequential shifts of covert attention take place during reading is actually accurate. This notion is clearly a fundamental aspect of the *E-Z Reader* model, as it not only predicts serial processing during reading but also enables the model to account for preview effects and foveal-on-parafoveal effects. However, there is in fact little evidence to suggest that sequential shifts of attention occur during reading (see Blanchard, McConkie, Zola & Wolverton, 1984), implying that the validity of the model may be resting on a fundamentally inaccurate premise. Additionally, while the authors of *E-Z Reader* imply that reading is like surrogate listening, since they state that “The serial allocation of attention is necessary because it preserves the temporal order of words,” (Reichle et al., 2003), it does not appear to be the case that reading is like this. As Kennedy (2003) points out, reading is in fact a spatial activity in which text can be inspected (and re-inspected) at will. Indeed, research has shown that readers know where previous words lie (e.g. Radach & McConkie, 1998), suggesting that spatially coded information is used during reading (e.g. Kennedy & Murray, 1987b; Pynte, Kennedy, Murray & Courrieu, 1988). Thus, in contrast to claims made by Ferreira and Clifton (1986), the syntactic processing strategies employed by readers and listeners appear to differ.

1.4.11. Can the model handle sentence-level effects?

Predictability must, by definition, be a sentence-level effect. Since the predictability of the words used in simulations of the model were determined via a norming experiment, then in the model, predictability effects arise (at least partly) due to the nature of prior sentential context. This means that although the verbal model of the *E-Z Reader* is vague about the nature of the effect, it at least predicts that the effect is one operating at the level of the sentence. However, it should be recalled that the model also proposes that predictability exerts its influence at the level of lexical access, and as previously discussed, it is not yet clear as to whether this is actually the case. Thus, further investigation into the nature of predictability effects is clearly required in order that they be successfully incorporated into models of reading.

During reading there are clearly many other high-level sentential processes in operation, but up until the latest version of the *E-Z Reader* model (10), these processes have largely been ignored. *E-Z Reader* 10 attempts to account for both clause-wrap up and plausibility effects. Clause wrap-up effects arise in the form of increased fixations on a word, and longer saccades from a word, when the word ends a punctuated-marked clause or sentence than when it doesn't (e.g. Hill & Murray, 2000; Rayner, Kambe & Duffy, 2000; Hirotani, Frazier & Rayner, 2006; Kennedy & Pynte, 2008). These effects have traditionally thought to be the result of integrative processing that occurs at the end of a clause (e.g. Carpenter & Just, 1980; Rayner et al., 2000, although see Hill & Murray, 2000, for an alternative explanation). With this assumption in mind, and given that in the model post-lexical processing on *n* must complete before the meaning of *n* + 1 has been accessed, Reichle et al. (2009) propose that the model should predict longer fixation durations on *n* and that there should be more regressions back to *n,* when n is a clause-final word (e.g. "...washed the *dishes*, already...." than when it is a non-clause-final word (e.g. "...washed the *dishes* already....". The authors thus attempted to simulate this pattern of effects using the Schilling et al. data-set and data from the Rayner, Kambe and Duffy (2000) experiment. In order to simulate the non-clause-final condition, the duration of the post-lexical integration stage on the target word was increased to 100ms. The rationale was that although non-clause-final, it was the last non-adjunct part of a clause and this might cause some integration difficulty. Additionally, in order to reflect clause wrap-up, the duration of the post-lexical integration stage on the target word was increased to 250ms in the clause-final condition. Simulations of *E-Z Reader* 10 revealed that the model predicted longer fixation durations on clause-final words, as well as more re-fixations on and more regressions back to those words, than on clause-non-final words. Thus, the model simulations seem to suggest that *E-Z Reader* can account for clause-wrap up effects which are modulated by post-lexical processing.

The *E-Z Reader* model also attempts to account for plausibility effects (these are discussed in depth in Chapter 2) during reading (e.g. Murray, 1998; Murray & Rowan, 1998; Kennedy, Murray & Boissiere, 2004; Warren & McConnell, 2007; Rayner, Warren, Juhasz & Liversedge, 2004). Plausibility refers to the likelihood of the event being described in a sentence, actually being true. An experiment by Warren and McConnell (2007) showed that both gaze durations and total reading times were shorter on a word which was (1) both possible and plausible given the prior sentence context, than on a word which was (2) possible but implausible. Thus, they obtained effects of plausibility but only in later eye-movement measures as there was no effect in first fixation durations, implying that plausibility may exert its effect at the post-access level. They further showed that first fixation durations were longer on a word which was (3) impossible but also implausible, than on a word in (2), indicating that violations of possibility, or selectional restriction, are detected early and may therefore affect the initial stages of word-processing. Reichle et al. attempted to simulate this pattern of effects also by employing the Schilling et al. data-set and the Warren and McConnell experimental data. In order to simulate the possible-implausible condition, the duration of the post-lexical integration stage on the target word was increased to 200ms to reflect post-lexical processing difficulty that might occur when readers generate a discourse model for an implausible event. To simulate the impossible-implausible condition, the duration of the post-lexical integration stage on the target word was also increased to 200ms, while the rate of lexical processing was attenuated by the selectional restriction violation. Simulations of *E-Z Reader* 10 showed that the model could simulate the correct pattern of effects.

(1) “The man used a strainer to drain the thin *spaghetti*....”

(2) “The man used a blow-dryer to dry the thin *spaghetti*...”

(3) “The man used a photo to blackmail the thin *spaghetti*...”

It is clear that *E-Z Reader* is making some progress on modelling effects arising at the level of the sentence, effects which have until now, largely been ignored by models of reading. However, there is still a lot more work to be done in this area. For example, at present, the *E-Z Reader* cannot model syntactic parsing. A more fundamental point is whether it is even possible for the *E-Z Reader* to account for all of the high-level sentential effects reported in the literature given that in the model, the engine driving eye-movements is lexical processing.

1.5. The SWIFT model

1.5.1. Background to the model

Engbert et al. (2002) put forward the SWIFT model, an acronym for 'Saccade-generation With Inhibition of Foveal Targets', which aims to give an alternative account of eye-movement control during reading to that proposed by processing models such as *E-Z Reader*. Since the original SWIFT model, two subsequent versions have been proposed. In one of these versions, only minor refinements to the model were made (Richter et al., 2006), while the other (Engbert et al., 2005), entitled SWIFT II, aimed to give a more comprehensive account of the factors known to influence eye-movements during reading. The up-coming section therefore contains a discussion of the most recent version of the model (SWIFT II) and highlights the main modifications of the other versions which led to SWIFT II. It also comments on how well the model can account for the phenomena known to occur during silent reading and how well it fits the data.

The fixation durations and other data predicted by SWIFT II were obtained by simulating the model using data from the Potsdam Sentence Corpus (Kliegl, Grabner, Rolfs & Engbert, 2004). This data set includes 1138 words and was obtained by recording the eye movements of 230 German participants as they read 144 sentences. The words were separated into five classes of word-frequency (1-10, 11-100, 101-1000, 1001-10,000 and 10,000 + counts per million). The predictability values of the words in the corpus were obtained by way of a norming study undertaken by 272 German participants. The sentences from the corpus were presented to participants in a random order and participants were asked to guess the first word of an unknown sentence by entering it on a computer. The computer then presented the correct word, and participants then had to guess the second word and so on, until the end of the sentence. Not all participants read all sentences, this resulted in 83 complete predictability protocols for the 144 sentences.

Before giving a blow-by-blow account of how the SWIFT model accounts for eye movements during reading, the fundamental assumptions on which the model was built upon need to be highlighted. The first assumption is that there is a one-dimensional lexical activation field in which lexical activations are built up in parallel, meaning that SWIFT therefore adopts the dynamic-field approach (e.g. Erlhagen & Schoner, 2002; Spivey, 2007). The notion of the parallel build-up of lexical activations necessarily implies that processing is distributed over several words at a time rather than in a strict serial-sequential manner, which is of course what *E-Z Reader* proposes. The activation field establishes a salience map for target selection and the target for a saccade is the word (in the reader's current window of attention) which has won a "competition" among words with different activations. In the original model (Engbert et al., 2002), the attentional window was assumed to span four words, the currently fixated word (*n*), the word to the left of *n* and the two words to the right of *n*. However, this assumption was altered so that the attentional window could take into account different word lengths (Richter et al., 2006) and the processing gradient is now broken down to the level of the letter. Despite this modification, the width of the processing span to the left and to the right still approximates four words and is based on research which shows that for English readers, the perceptual span extends for about 19 characters: 4 to the left and 15 to the right of fixation (e.g. McConkie & Rayner, 1975; Rayner, 1986; Rayner & Bertera, 1979). A second principle of the model is that saccade timing is separated from saccade selection and is based on neurophysiological evidence which suggests that there are separate pathways for these processes (e.g. Carpenter, 2000; Findlay & Walker, 1999; Wurtz, 1996). The final fundamental assumption of the original SWIFT model is that saccade generation is a random process although it is inhibited by foveal processing (this aspect of the model is therefore similar to that proposed in Yang and McConkie's Competition-Interaction model). Thus, in the SWIFT model, and in contrast to the *E-Z Reader* model, the engine driving eye movements during reading is not lexical processing. Instead, saccades are initiated in order to maintain a mean rate of eye movements.

1.5.2. SWIFT II

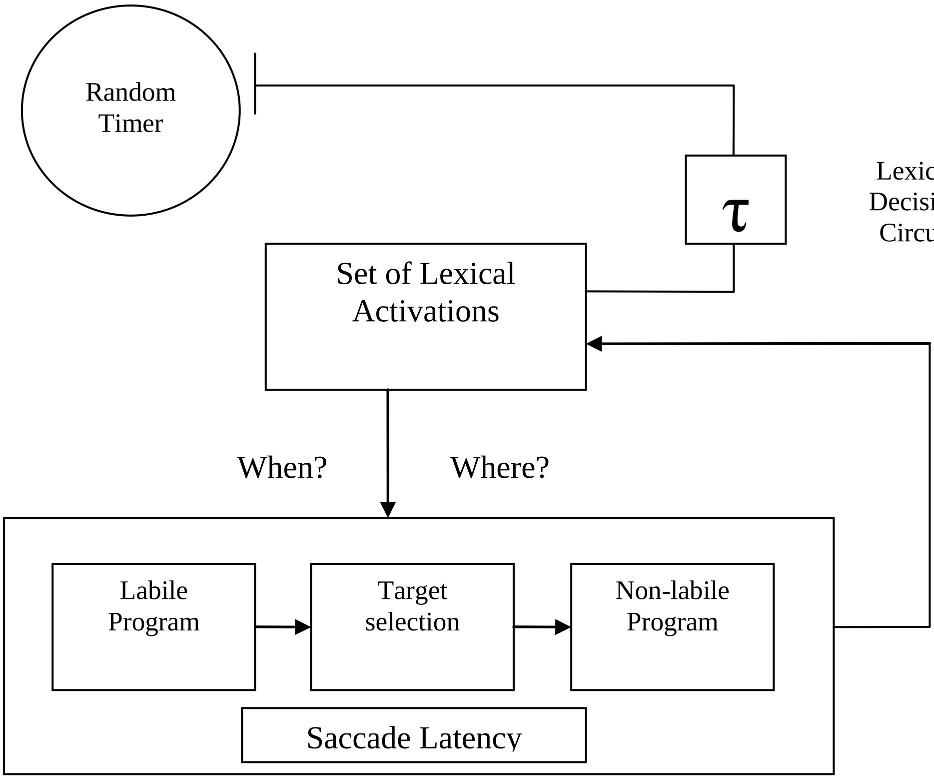


Figure 1.2. A schematic diagram of the SWIFT II model. Adapted from Engbert et al. (2005).

In the SWIFT model, as soon as a word appears in the reader's attentional window its lexical properties are "activated". This activation increases as the word begins to be processed and this takes place in a ‘pre-processing stage’. Thus similar to the *E-Z Reader* model, word-identification is assumed to consist of two stages: A lexical pre-processing stage and a lexical processing stage. During the lexical pre-processing stage, information about a word’s low-level properties is obtained (e.g. word-length and the initial tri-gram frequency) causing lexical activity to increase from zero. The pre-processing stage completes when the maximum lexical activity value of a word is reached and this depends on the difficulty of a word which is a function of the log frequency of the word and is also modulated by logit word-predictability. In the model, low-frequency words have a higher maximum lexical activity value than high-frequency words, meaning that it will take longer for the maximum lexical activity of a low-frequency word to be reached. The main purpose of the pre-processing stage is to include a word into the possible set of saccade targets as soon as it appears in the reader’s attentional window: As a word’s lexical activity increases, the probability of selecting this word as a target increases (the issue of target selection will be returned to later).

Following completion of the lexical pre-processing stage, the second (longer) stage of lexical processing begins, during which, lexical activity decreases: When lexical activity reaches zero, lexical access is completed (and is assumed to be a process of memory retrieval). In the model, lexical processing rate is a function of the physical distance of a letter from the current fixation position. Thus letters (and therefore words) that are closer to the point of fixation will be processed faster than letters which are farther away and this aspect of the model allows it to account for word-length effects. It will be recalled that processing occurs across an asymmetrical attentional window which encompasses approximately four words. Thus in the model, lexical processing rate is assumed to follow an asymmetric Gaussian distribution so that the word being fixated is processed most rapidly while n – 1 and n + 1 are processed less rapidly and n + 2 is processed least rapidly.

Similar to *E-Z Reader*, saccadic programming follows the first stage of lexical processing and consists of a labile and non-labile stage. In contrast to *E-Z Reader* however, saccade initiation is separated from that of saccade target selection; saccade initiation is largely independent of lexical processing while target selection is not. In the SWIFT model, the labile stage of saccadic programming is autonomous and is initiated after a time interval which approximates the duration of the prior fixation. Initially, Engbert et al. (2002) suggested that saccade generation is completely random, however, since this would lead to random fixation durations, the authors introduced a foveal inhibition process which increases fixation durations on difficult words. Thus, on some occasions the time interval prior to saccadic programming can be extended, resulting in an extended fixation (of up to 65ms), if the word being fixated is difficult to process. A further point to be made regarding the labile stage is that during this stage, the saccade can be cancelled or modified. This aspect of the model of course differs from *E-Z Reader* as in the latter model, saccades can only be cancelled.

Following the labile stage (which takes 150ms), the target for a saccade is selected based on Luce's (1959) choice rule which states that the preference for selecting one item over another is not affected by the number of alternative items available. In the majority of the time, the target is assumed to be the next closest word to the right of the currently fixated word. This is for two reasons. First, the model assumes that the eyes generally always move forward (to n + 1) unless the current word (n) is re-fixated or n – 1 is regressed to or n + 1 is skipped. Second, the target for a saccade is the word with the highest lexical activity and this will be $n + 1$ since it will be the word closest to the current point of fixation. That is, in the model, words closest to the current point of fixation are processed faster, so $n + 1$ will have been pre-processed to a fairly high degree (while the eyes were fixating n) and will therefore have high lexical activity. However, if the lexical activation of all of the words in the current attentional window happens to be zero, the model proposes that a target will be selected randomly. Following target selection, the non-labile stage is entered (which takes 50ms to complete) and this is influenced by the intended saccade amplitude. Finally, the saccade is executed (this takes 25ms). During the saccade, pre-processing pauses since there is no visual input during this time (e.g. Matin, 1974) with a temporal delay of 50ms (since there is an eye-brain lag of around 50ms) while lexical processing continues.

1.5.3. How the model accounts for frequency and predictability effects

SWIFT successfully predicts that high-frequency words will be processed faster than low-frequency words. This is because in the model, pre-processing time increases with lexical activity: Low-frequency words have a higher maximum lexical activity value than high-frequency words meaning that it will take longer for the 'threshold' of low-frequency words to be reached. Simulations of the model using the Potsdam sentence corpus revealed that the model was able to successfully predict frequency effects (although fixation durations for low-frequency words were not as long as those obtained in the Potsdam corpus data). With regard to word-predictability, it is assumed that a highly predictable word can be guessed from the prior sentence context with minimal visual input. This means that lexical activity for a perfectly predictable word will in fact be zero and that the activation of high-predictable words which are not perfectly predictable (while in parafoveal vision) will build up more slowly than for a low-predictable word and thus, pre-processing rate will be *slower* for a high-predictable word than for a low-predictable word. However, processing rate increases with predictability during the lexical processing stage so that overall, the model successfully predicts that predictable words will be processed faster than unpredictable words. A further point to be made here is that since word-predictability is assumed to modulate pre-processing time, this suggests that it can potentially exert an earlier effect on word-processing time than that predicted by the *E-Z Reader* model.

1.5.4. Does the model predict additive or interactive effects of frequency and predictability?

In the SWIFT model, the processes of word-frequency and word-predictability are dissociated: Word-frequency determines the rate at which a word will be pre-processed while word-predictability modulates pre-processing time. The rationale for not combining word-frequency and predictability in a single equation for word-difficulty is because the authors propose that while word frequency information unfolds during the word-recognition process, word predictability is independent of visual input. Thus, the model does not make specific assumptions regarding the relationship of the two variables on fixation durations, meaning that it can potentially account for additive or interactive effects of the two variables.

1.5.5. How the model accounts for word-skipping effects

The SWIFT model attempts to account for the skipping of predictable and high-frequency words. It will be recalled that in the model, the target of the next saccade is the word which has the largest current lexical activity. Since it is assumed that perfectly predictable words have a lexical activity of zero, this means that the model can successfully account for the high skipping rate associated with very predictable words. Additionally, since pre-processing of predictable words (which are not perfectly predictable) occurs fairly slowly, this means that these words will initially have a low lexical activity and therefore will be more likely to be skipped. The model accounts for the finding that high-frequency words are skipped more often than low-frequency words by proposing that they are lexically processed completely in the parafovea.

Similar to *E-Z Reader*, but for different reasons, SWIFT also predicts an increased fixation duration on the word (*n*) immediately prior to a skipped word (*n* + 1). In SWIFT, an increased fixation duration on a word will mean that more parafoveal information can accumulate and thus increase the likelihood of the up-coming word being skipped.

1.5.6. How the model accounts for effects relating to parafoveal preview.

SWIFT can account for the fact that a preview advantage will be obtained for high-frequency words since pre-processing of *n* + 1 during the fixation of *n* is fast for these words, meaning that when *n* + 1 is actually fixated, less time for the lexical completion stage will be needed. It can also account for the preview advantage obtained for predictable words. It will be recalled that during the fixation of *n*, pre-processing of *n* + 1 is slow when it is predictable, however, the model also predicts that highly predictable words can be processed in the parafovea, thus allowing it to account for parafoveal preview benefit obtained on predictable words. SWIFT also predicts that there will be a greater preview advantage on *n* + 1 when *n* is a short word since more parafoveal processing can take place during the fixation of *n*.

The SWIFT model can also account for 'foveal-on-parafoveal' effects relating to word-frequency and predictability: According to the model, inspection times on *n* + 1 (when it is eventually fixated), will be longer when *n* is of low-frequency and/or unpredictable, this is because, when *n* is difficult, foveal inhibition is extended, resulting in a reduction of parafoveal processing. In contrast to *E-Z Reader*, SWIFT also predicts that granting preview of *n* + 2 during a fixation on *n* should facilitate later processing of *n* + 2 since the attentional span encompasses both of these words. However, while some experimental manipulations have provided support for this hypothesis (e.g. Kliegl et al., 2007; Radach & Glover, 2007; Wang, Inhoff & Radach, 2009) others have not (e.g. Rayner, Juhasz & Brown, 2007; Angele, Slattery, Yang, Kliegl & Rayner, 2008).

1.5.7. Can the model account for spill-over effects?

Given that spill-over effects are essentially foveal-on-parafoveal effects, then as previously discussed, these would arise as a result of the time-delayed foveal inhibition mechanism. The operation of this mechanism means that fixation duration on a currently fixated word is controlled by inhibition from the last word.

1.5.8. Can the model account for where words are fixated?

Similar to the *E-Z Reader* model, in SWIFT it is assumed that saccades are aimed towards the centre of words (the optimal viewing position). However, simulations of the model revealed that due to the asymmetrical distribution of lexical processing rate, initial fixations were shifted to the left of the centre of a word as word-length increased. Nevertheless, this allows the model to account for the tendency for the eyes to land on the preferred viewing location (Rayner, 1979). In the model, fixation positions are also shifted due to systematic range errors and random errors. With regard to the former, parameters are included in which long saccades overshoot the centre of a word while short saccades undershoot word-centres. Simulations of the model using the Potsdam sentence corpus revealed that the model was successfully able to predict the finding that initial landing position is a function of launch position and also word length. That is, the simulations revealed that the eyes were predicted to land nearer the end of words when the words were long and the saccades were from near launch sites, whereas they were predicted to land nearer the beginnings of words which were short in length and from far launch sites.

As previously discussed, systematic errors can sometimes result in mislocated fixations. In SWIFT, it is proposed that misguided saccades can be corrected by starting a new saccade program, if there is no labile saccade program already active. On these occasions, it is proposed that the interval between the two program initiations will be short (since neurophysiological findings suggest that gaze errors are monitored continuously and are therefore easily detected), and as a consequence, shorter fixation durations near word boundaries will be obtained. This mechanism therefore accounts for the IOVP effect (Vitu, et al., 2001), in which fixation durations are longer on word-centres and shorter at the beginning and ends of words. Simulations of the model using the Potsdam corpus revealed that the model could reproduce the IOVP effect for the measure of single fixation duration.

A final point to be made here is that since a fundamental assumption of the SWIFT model is that words are processed in parallel, the model can theoretically account for the fact that the initial orthography of a parafoveal word can determine where this word will be fixated.

1.5.9. Can the model account for re-fixations?

The SWIFT model can account for both intra- and inter-word re-fixations. With regard to the former, if lexical processing of a word has begun and after a while, lexical activity is still fairly high, the word can be selected as a target for a second time. This mechanism accounts for the fact that low-frequency and unpredictable words are more likely to be re-fixated than high-frequency and predictable words since in the model, lexical activity is prolonged in the case of more difficult words. According to SWIFT, intra-word re-fixations are also a function of initial landing position which also depends on word length. It will be recalled that research suggests that the probability of making a refixation increases when the eyes land near the beginning or end of words and the former is more likely to happen when the word is long, while the latter is more likely to happen when the word is short. Simulations of the model using the Potsdam sentence corpus confirmed this pattern of effects.

SWIFT can also account for inter-word re-fixations, or regressions, and two different types of these can occur in the model. The first type, which Engbert et al., (2002) has referred to as a ‘local’ regression, arises due to the nature of the saccade target mechanism. That is, any word within the current attentional window can be the target for a saccade as long as its lexical activity is greater than zero. The second type which the authors refer to as a ‘global’ regression, arises due to incomplete lexical processing. That is, according to the model, the eyes can sometimes move on before a word is completely processed, meaning that some residual lexical activity will remain with this word, and as long as there is some lexical activity remaining (even though the word is no longer in the attentional window), this word can be regressed to. The residual activity is assumed to remain at a constant level as long as the word is no longer in the reader’s attentional window, whereas if the word is still in the window of attention, the residual activity is presumed to stay at its last value until it is no longer in the attentional window. This aspect of the model allows it to account for long regressions. It also implies that more regressions should be made to words that have been skipped (it will be recalled that the model predicts that words with low lexical activity will be skipped) and simulations of the model using the Potsdam sentence corpus confirmed this hypothesis.

In SWIFT, a number of regressions are also predicted to be mislocated re-fixations arising from oculomotor error.

1.5.10. Does the model predict any serial processing?

In SWIFT, the lexical activity of words build up in parallel, thus implying that words are mostly processed in parallel. Indeed, the model predicts that in the majority of the time, three to four words are processed simultaneously. This of course means that the model can theoretically account for parafoveal-on-foveal effects (although there is in fact no explicit mechanism for the modulation of foveal processing by processing of the word(s) to the right of word *n*). Model simulations using the Potsdam sentence corpus revealed that in SWIFT, serial processing only occurs towards the end of a sentence and this is assumed to be because the rest of the sentence has been thoroughly processed by then.

1.5.11. Can the model handle sentence-level effects?

SWIFT can account for predictability effects which must be at least partly a sentence-level effect. However, at the time of writing, there has been no attempt as yet to model any other sentence-level effects.

Chapter 2:

Effects and theories of predictability, plausibility and word-frequency

2.1. Overview of aims of chapter

This chapter considers the different types of predictability effect which have been reported in the literature and the theories that have been proposed to account for them. Specifically, whether or not readers make predictions about up-coming words, and whether co-occurrence probability, transitional probability, or surprisal, contribute towards the predictability effect will be considered. A running theme throughout this thesis is whether the predictability effect may be best explained by a Modular or Interactive theory of language processing; thus evidence which bears on this issue, including that from the literature on plausibility and context effects, will also be discussed. It should be recalled that one of the aims of this thesis is to identify the relationship between word-frequency and predictability on word-encoding time, thus the effects of word-frequency and what the literature suggests thus far regarding its relationship with word-predictability will be considered. The chapter concludes with an evaluation of the literature concerning serial versus parallel processing in reading.

2.2. Effects and theories of word-predictability

2.2.1. Methods of determining predictability

In order to investigate the effects of word predictability obtained via an orthogonally designed experiment, researchers must first construct experimental sentences or paragraphs in which the context is built up sufficiently so that a critical word (the target word) in the sentence can be either easily predicted or is difficult to predict. The researcher must then test the validity of the experimental items. There are two main methods of doing this. One method is to give a group of participants a task in which they are presented with sentences up to and including the target word and then asking them to indicate on a scale of 1-5 (for example) how well the target word fits into the sentence. The higher the rating the target word receives, the more predictable it is considered to be. The other method is to employ a cloze task and there are two versions of this task. In the “traditional” version, participants are given sentence fragments up to the target word and are asked to write down the word they think most likely comes next in each of the fragments. However, if an experimenter wishes to determine the predictability of more than one word in a sentence, which is common during corpus analysis, then an “incremental” version of the cloze task may be employed. In this task, participants are usually presented with the first word of a sentence (on a computer screen) and then asked to guess the second word. The computer informs the participant as to whether their guess was correct, then the participant is asked to guess the next word in the sentence, and so on until all of the words in the sentence have been guessed.

In the cloze task, if participants only manage to guess the correct word less than 10% of the time, then the word can be defined as unpredictable, whereas words that are correctly guessed more than 60% of the time are defined as predictable (Rayner & Well, 1996). In order to ensure a good spread of predictability, it is in fact preferable that ratings for high-predictable words are as close to 100% as possible and that ratings for low-predictable words are as close to 0% as possible.

The cloze task is more commonly used by experimenters than the “scale” task since it demonstrates greater validity. That is, in the cloze task, participants are asked to actually provide the word as opposed to just speculate as to whether the word is predictable or not, which is essentially what they are asked to do in the scale task. For this reason, the cloze task is used to establish the predictability ratings of the stimuli employed in the experiments reported in this thesis. The reader should be made aware however, that there are also disadvantages of using the cloze task. For example, the nature of the task means that it is quite subjective, and it has also been criticized (e.g. Reichle, Rayner & Pollatsek, 2003) for not representing normal reading in which readers obtain a parafoveal preview of up-coming words.

2.2.2. Types of predictability effects reported in the literature

The predictability of a word has been shown to affect both the temporal and spatial aspects of eye movement control. With respect to the temporal aspect, words that are highly predictable from the preceding context are processed more quickly than words that are not as predictable. Analysis of when exactly this effect occurs can reveal something about the time-frame, and therefore the nature, of the predictability effect. A number of studies have shown that word predictability affects first fixation durations (Rayner, Ashby, Pollatsek & Reichle, 2004; Binder, Pollatsek & Rayner, 1999; Altarriba, Kroll, Sholl & Rayner, 1996). Since first fixation duration is a very early measure of word encoding, it is often assumed to capture lexical access. Thus, it could be the case that predictable words are accessed from the lexicon faster than unpredictable words. However, predictability also influences “mid” measures of word encoding such as gaze durations (e.g. Frisson, Rayner & Pickering, 2005; Rayner et al., 2004; Lavigne, Vitu & d’Ydewalle, 2000; Binder et al., 1999; Rayner & Well, 1996; Balota, Pollatsek & Rayner, 1985) and “late” measures such as total reading times (e.g. Calvo & Meseguer, 2002; Rayner & Well, 1996; Ehrlich & Rayner, 1981) and the probability of making a regression (e.g. Calvo & Meseguer, 2002; Inhoff, 1984; Ehrlich & Rayner, 1981). Late influences of cognitive variables are usually associated with integration of individual word-meanings to either the meaning of the phrase surrounding the critical word or the overall meaning of the sentence. Indeed by definition, more predictable words are easier to integrate than less predictable words, suggesting that this could be why the former are processed faster than the latter. If the predictability effect is the result of post-lexical integration then this process must occur fairly rapidly given that predictability also influences first fixation durations.

With regard to the spatial aspect of eye movement control, a study by Lavigne et al. (2000) has shown that first fixations land further into high-frequency predictable words than high-frequency unpredictable words (when the saccade is launched 5-7 character spaces from the target word). This phenomenon suggests that the predictability of a word (that hasn’t even been fixated yet) can determine where the eyes will land in the word when it is eventually fixated. This proposal is of course controversial as it contradicts the notion of serial processing in reading. Other studies have shown however, that word predictability appears to have no effect on where the eyes initially land in a word (Vainio, Hyona & Pajunen, 2009; Rayner, Binder, Ashby & Pollatsek, 2001; Vonk, Radach & Van Rijn, 2000). Somewhat paradoxically, the predictability of a word does however, affect skipping rate: Predictable words are less likely to be directly fixated than unpredictable words (Drieghe, Brysbaert, Desmet & De Baecke, 2004; Rayner et al.. 2004; Binder et al., 1999; Rayner & Well, 1996; Altarriba et al., 1996; Schustack, Ehrlich & Rayner, 1987; Balota et al., 1985; Ehrlich

& Rayner, 1981, although c.f. Zola, 1984), suggesting that there may be different mechanisms for determining saccade targets and actual landing positions in words.

The inflated skipping rate for predictable words could be because they are processed to a greater extent than unpredictable words while in the parafovea. This hypothesis is of course consistent with the predictions of the *E-Z Reader* model (see previous chapter). Alternatively, it could be because predictable words are guessed from the prior sentence context (with minimum visual input), meaning that fixation of these words is not required. This idea is consistent with the predictions of SWIFT. To date, the evidence which bears on this issue is mixed. That is, while Brysbaert & Vitu (1998) for example, provide evidence to suggest that the decision to skip a word is made via an educated guess based on coarse visual information such as word length, others argue (e.g. Drieghe, Rayner & Pollatsek, 2005) that word-skipping is based on at least partial word-recognition in parafoveal vision.

2.2.3. What is the function of the relationship between word-predictability and word-processing time?

To date, there have been very few orthogonally designed experiments which examine the function of the relationship between word-predictability and word-processing time. It is important to determine the function of the relationship since this can help to reveal the nature of the predictability effect. To give an example, if the function relating word-predictability and word-processing time were shown to be a continuous monotonic decreasing one, as opposed to a step-wise or dog-leg one, then this would provide evidence for models of word-recognition which predict a graded effect of predictability in which word-recognition time decreases as predictability increases.

An example of one study which has addressed this issue is that by Rayner and Well (1996). In Rayner and Well's study, participants' eye-movements were recorded as they read sentences which contained a target word which was either highly-predictable, medium-predictable or unpredictable given the preceding sentence context. The mean predictability ratings for each of the predictability conditions were 86%, 41% and 4% respectively. The authors found that there was no significant difference in processing time between the high- and medium- predictable words in the measure of first fixation duration (239ms versus 240ms), gaze duration (261ms versus 261ms) or total reading time (294ms versus 301ms). However, gaze durations and total reading times were significantly longer for the unpredictable words than for the medium- and high- predictable words. These outcomes have a number of important implications. First, they suggest that the relationship between word-predictability and word-processing time is not a strict monotonic decreasing one. Second, they imply that predictability effects on fixation durations act like frequency effects in which small differences at the low end of the scale have a bigger effect than small differences at the high end of the scale. However, these conclusions can only be tentatively drawn since there were a number of discrepancies in Rayner and Well's experimental items. First, the target word and sentence were not controlled between predictability conditions. Second, the predictability ratings for the medium-predictable words obtained in their cloze task ranged from 13%-68%, meaning that the medium predictable condition was in fact made up of both fairly predictable and fairly unpredictable words. If the medium-predictable condition was mostly made up of medium-high predictable words then this could explain why there was no difference in fixation durations between the high- and medium- predictable words. A further issue is that the authors only employed three levels of predictability. Clearly by including more levels, for example, medium-high-predictable and medium-low-predictable, this would enable a more thorough examination of the function of the relationship between word-predictability and word-processing time.

A study which is similar in nature to Rayner and Well's (1996), although it focuses on the effect of word-predictability on the eye movements of Chinese readers, has been carried out by Rayner, Li, Juhasz and Yan (2005). In Rayner et al.'s (2005) experiment, eye-movements were recorded as Chinese participants read sentences in which the predictability of a defined target word was either high (mean predictability rating = 85%, range = 72% - 100%), medium (mean predictability rating = 36%, range = 11-67%) or low (mean predictability rating = 4%, range = 2-8%), depending on the preceding sentence context. The results of this experiment were slightly different to that obtained by Rayner and Well. This is because, although there was no significant difference in processing time between the high- and medium-predictable words in either first fixation durations (261ms vs 269ms) or in gaze (282ms vs 288ms), the direction of the (non-significant) differences were in the predicted direction. That is, inspection times decreased as predictability increased. Additionally, gaze durations were significantly longer for the low-predictable words (330ms) than for the medium-predictable words (288ms). Thus, the Rayner et al. (2005) study provides some evidence to suggest that word-predictability and word-processing time follow a monotonic decreasing function. It should be noted however, that given that Chinese text differs markedly from English text, these studies are only comparable to a certain extent. Furthermore, the problems with the Rayner and Well materials, highlighted above, were also present in the Rayner et al. study. That is, the target word and sentence were not controlled between predictability conditions and the predictability ratings for the medium-predictable condition varied markedly (range =

11 – 67%). Thus, arguably, the Rayner et al. study does not provide an adequate investigation into the function relating word-predictability and word-processing time either.

A further relevant study worthy of discussion here is that by Hyona (1993). In Hyona's study, participants' eye-movements were tracked as they read passages in which a defined target word was either predictable or unpredictable depending on the discourse of the passage. Hyona found no significant predictability effect in either first fixation duration or in gaze duration. Hyona's study appears to be the only one in the literature which simultaneously reports null effects of predictability in both of these measures, however, it appears that these null effects are due to the small difference in predictability ratings achieved in the cloze task: The mean predictability ratings were 65% for the predictable targets and 32% for the unpredictable targets, a difference of only 33%. It is clear that the unpredictable target words were nowhere near as unpredictable as they could have been. Thus, Hyona's study suggests that a fairly large spread of predictability is needed in order to obtain predictability effects.

The research described above highlights a number of issues which remain unresolved. These include, determining whether word-predictability and word-processing time follow a strict monotonic decreasing function or not, and whether predictability effects act like frequency effects. To date, no-one has investigated whether predictability effects can be obtained between medium-low and unpredictable words. An experiment which includes these two conditions would be helpful in addressing the above issues and is therefore reported in Chapter 6. An alternative way to examine the function of the relationship between word-predictability and word-processing time is to employ linear mixed effects (*lme*) analyses in which predictability can be entered as a continuous variable, this methodology is employed in Chapters 7 and 8.

2.2.4. Do we make predictions about up-coming words?

Predictability effects are well-reported in the literature, however less is known about the nature of the effects. One view-point is that while we're reading we make predictions, possibly at an unconscious level, about up-coming words. Early models of reading, such as the Hypothesis Testing and Guessing Game models (Goodman, 1967; Haber, 1978; Hochberg, 1978; Levin & Kaplan, 1970; Smith, 1971), placed great emphasis on prediction. According to these models, the reader uses the information provided by the context of the sentence, and the information available in parafoveal vision to generate a prediction about what the up-coming word will be. When the up-coming word is eventually fixated, the reader quickly "samples" the visual information (i.e. the word) and confirms whether the prediction is correct or not. This model can account for predictability effects as presumably less predictions are generated when contextual constraint is high than when it is low, meaning that it will take less time for a match to be made between the generated lexical candidates and the correct target word when contextual constraint is high. The Hypothesis Testing Theory received a lot of criticism at the time, with some arguing that readers only seem to be good at predicting very predictable words (this is in fact demonstrated in cloze tasks) and that it seems inconceivable that we constantly make predictions during sentence parsing if for the majority of the time the prediction is bound to be incorrect. Indeed, the process of "correcting" incorrect predictions would not be cognitively efficient. However, there is in fact a growing body of research which suggests that we do make predictions during language processing.

There is evidence from Event Related Potential (ERP), self-paced reading and eye-tracking studies which suggest that we make predictions about up-coming words during reading. De Long, Urbach and Kutas (2005), for example, carried out a study which measured ERP's and eye-movements concurrently, with the aim of determining whether readers pre-activate specific articles and nouns before their occurrence. In their study, participants read sentences in which the final noun was either more predictable (1a) and (1c) or less predictable (1b) and (1d) given the preceding sentence context, additionally, the article preceding the noun could be either appropriate (1a) and (1b) or inappropriate (1c) and (1d) given the nature of the up-coming noun.

(1a) "The day was breezy so the boy went outside to fly *a kite*".

(1b) "The day was breezy so the boy went outside to fly *an airplane*".

(1c) "The day was breezy so the boy went outside to fly *an kite*".

(1d) "The day was breezy so the boy went outside to fly *a airplane*".

The authors obtained two main findings which are of significance to the literature. First, they found a predictability effect: The amplitude of N400s (the neural response to potentially meaningful items), became less negative when participants encountered nouns which were highly predictable given the preceding context than nouns which were less predictable. This finding is in line with past research (e.g. Kutas & Hilyard, 1980) which has shown that the N400 increases in magnitude (becomes more negative) in response to nouns that do not fit with the preceding sentence context. De Long et al. then argued that their obtained predictability effect was due to prediction rather than integration. This is because the N400 was also less negative for the appropriate articles than for the inappropriate articles. That is, when the reader viewed an article which was inappropriate given the up-coming word, the N400 on the article became more negative, suggesting that the reader had predicted the up-coming noun and therefore knew (either consciously or subconsciously) that the article was inappropriate. However, attention should be drawn to the fact that in De Long et al.'s study, it is highly likely that the up-coming noun was visible to readers while they were fixating the article (the article always consisted of only one or two letters). That is, the effect could in fact be a form of parafoveal-on-foveal effect.

The results of a Dutch self-paced reading study carried out by Van Berkum, Brown, Zwitserlood, Kooijman and Hagoort (2005) have also provided evidence to suggest that we make predictions about up-coming words. Van Berkum et al. presented participants with two-sentence mini-stories which were highly constrained towards a defined target noun. In the mini-stories, the inflectional suffix of the second-last adjective was either consistent or inconsistent with an up-coming predictable noun (the second-last adjective and the predictable noun were separated by three other words). In order to avoid agreement violations, the authors ensured that when the critical adjective inflection did not agree with the predictable noun, a semantically coherent alternative noun that did agree with the critical adjective inflection was presented. The results of the study revealed that reading times on the word preceding the critical noun were 21ms (significantly) longer when the up-coming predictable noun did not agree with the inflection of the critical adjective than when it did. Thus, similar to DeLong et al.'s results, this outcome suggests that the up-coming predictable noun was anticipated.

A recent study by Kennedy, Pynte, Murray and Paul (submitted), in which participants' eye-movements were tracked as they read sentences from the Dundee corpus (Kennedy, Hill & Pynte, 2003), may also provide evidence to suggest that readers form predictions about up-coming words. Specifically, these authors found that inspection times on a currently fixated word increased as the predictability of an up-coming word increased[4]. This inverted predictability effect has been reported previously by Kliegl, Nuthmann and Engbert (2006) in an analysis of the Potsdam corpus data (although it was not dependent upon the syntactic status of the foveal word). Kliegl et al. (2006) suggest that this effect occurs as the result of a memory retrieval mechanism cued by the prior sentence context. Specifically, readers may anticipate an up-coming word (*n*) if the sentence is heavily constrained towards (*n*) and will retrieve the as-yet-unfixated word from memory during fixation of the prior word (*n*-1). This 'cued memory retrieval' hypothesis therefore postulates both anticipatory and memory retrieval processes and predicts that processing time on a currently fixated word is inflated when the subsequent word is predictable. Kliegl et al. further propose that when the up-coming word is unpredictable, there is no anticipation, so the eyes are shifted to word *n* (as if the mind is sending the eyes to have a look), resulting in shorter inspection times on a currently fixated word (*n*-1). While Kliegl et al.'s hypothesis could account for inverted predictability effects, it is clear that evidence for a cued memory retrieval mechanism is required. If there were evidence for such a mechanism, then this would obviously mean that readers do form predictions about up-coming words.

[4] But only for cases when the foveal word was a content word and the up-coming word was subsequently fixated.

If it is the case that we make predictions about up-coming words then this implies that the predictability effect may be due to anticipation rather than integration of a word to its wider discourse. Since Van Berkum et al.'s and De Long et al.'s studies provide evidence of syntactic-based anticipation, a key question is whether syntactic comprehension involves prediction. There is in fact a body of research stemming from the work of Chomsky, which suggests that we know a grammar describing the structure of word-sequences (this grammar is formally known as a probabilistic grammar). Within this body there is a group of researchers (e.g. Hale, 2001; Levy, 2008) who have proposed that processing difficulty on a word is proportional to the word's surprisal within the sentence in which it appears. Surprisal is defined as the negative log probability of a word given the preceding words. Thus, the lower the probability of *n* appearing in a sentence, the more surprising it is, and the longer it will take to process this word. The notion of surprisal clearly assumes that we know a probabilistic grammar (indeed surprisal is calculated using a probabilistic context-free grammar) and that during sentence parsing, we form syntactic-based predictions about up-coming words.

Recently a study has been carried out which investigated whether surprisal could predict empirical predictability scores (as measured in a cloze task). Using data from the Potsdam sentence corpus (Kliegl, et al., 2006), Boston, Hale, Kliegl, Patil and Vasishth (2008) added two different versions/grammar types of surprisal (hierarchical phrase-structure and word-to-word dependencies) to a linear mixed effects model which already included a number of predictors shown to influence empirical predictability. The outcome was that neither the hierarchical phrase-structure or word-to word dependency version of surprisal had a statistically significant effect on predictability scores. That is, surprisal was not significantly correlated with predictability scores although the direction of the (non-significant) relationship was in the predicted direction: More surprising words were more difficult to predict.

Overall, there is clearly some evidence from the above research which suggests that we form syntactic-based expectations during reading comprehension, meaning that this could be what drives the predictability effect. Although the issue of syntactic-based expectations is not addressed in this thesis, one of the aims of experiments 1,2 3 and 4 (Chapters 4,5, 6 and 7) is to determine whether readers form expectations about up-coming words.

2.2.5. The role of parafoveal preview information during the processing of predictable and unpredictable words

The early Hypothesis Testing and Guessing Game models of reading proposed that reading was essentially a top-down process and the fact that bottom-up processing only played a minor role was a huge weakness of the models. A number of subsequent models were proposed which tried to place equal emphasis on top-down and bottom-up processing in reading. For example, in an early word-recognition model proposed by McClelland and O'Regan (1981), a modified version of the Logogen model (Morton, 1969), the process of word recognition is influenced by a number of factors including contextual constraint and parafoveal information. According to the model, when useful parafoveal information is available, and when the context is sufficiently constrained towards a particular word, these sources of information can be combined to provide sufficient activation for a logogen to surpass its threshold (this is the point at which a word is recognised). When the context is less constrained towards a particular word, more logogens will be activated. When many logogens are activated, they will inhibit each other, meaning that it will take longer for the correct logogen to surpass its threshold. This model also predicts that in less constraining sentences, more parafoveal preview information will be used in order to provide sufficient activation for a logogen to fire.

Whether there is in fact any evidence to suggest that parafoveal preview information is utilised during the processing of predictable and unpredictable words will be considered in this section by discussing eye-tracking studies which have investigated this issue. If it is the case that initial preview information is utilised during the processing of predictable and unpredictable words, then a related issue is whether the predictability effect is modulated by the type of preview information initially available in parafoveal vision.

An early study by Balota, Pollatsek and Rayner (1985), was one of the first to investigate what types of parafoveal preview information are utilised during the processing of predictable and unpredictable words. In the Balota et al. study, participants were presented with sentences that were either predictable or unpredictable given the preceding sentence context. The authors used sentence frames such as (2) below. In (2), the word 'cake' is the word most likely to follow the word 'wedding'. However, the word 'pies', could also fit into the sentence frame, although this word is fairly unpredictable given the preceding sentence context.

(2) 'Since the wedding was today, the baker rushed the wedding ____ to the reception'.

In Balota et al.'s study, the type of preview that the reader obtained of the target word was also manipulated. The following examples relate to those used when the target word was the predictable word 'cake': The preview was either identical to the target word (e.g. 'cake'), visually similar to the target word (e.g. 'cahc'), semantically related and visually dissimilar (e.g. 'pies'), visually dissimilar (e.g. 'picz') or semantically anomalous and visually dissimilar (e.g. 'bomb'). The contingent boundary procedure (Rayner, 1975b) was also employed so that one of these previews was present in parafoveal vision while the eyes were fixating the pre-target word, but when the eyes left the pre-target word, the target-preview changed back to its correct form (e.g. 'cake'). Balota et al.'s study revealed a number of findings which are of theoretical importance. First, gaze durations on predictable words were significantly shorter following the identical preview than any of the other preview conditions, suggesting that preview information is utilised during the processing of predictable words. This finding is also consistent with a vast amount of research which suggests that there is a preview benefit from having a valid preview of a word prior to fixating it (Balota & Rayner, 1983; Henderson & Ferreira, 1990; Inhoff, 1989; Kennison & Clifton, 1995; Pollatsek, Lesch, Morris & Rayner, 1992; Rayner, 1975b; Rayner, Well, Pollatsek & Bertera, 1982; Schroyens, Vitu, Brysbaert & d'Ydewalle, 1999; Sereno & Rayner, 2000). Second, gaze durations on unpredictable words were also significantly shorter following the identical preview than any other preview (except for the visually similar preview), suggesting that parafoveal preview information is also used during the processing of unpredictable words. The fact that there was no difference between the identical and visually similar conditions in processing time on the unpredictable words, while there was for predictable words, implies that greater preview information was extracted when the target word was predictable. This outcome appears to differ from the predictions of the interactive-logogen model described above, and the *E-Z Reader* and SWIFT models (see previous chapter) which assume that less visual processing takes place for predictable words.

Balota et al.'s study also revealed that there was an effect of predictability following the identical preview and that the size of this effect only slightly decreased following the visually similar preview. However, following the visually dissimilar preview, the predictability effect disappeared. Taken together, these latter outcomes suggest that the predictability effect is modulated by initial preview information since there was more facilitation (or less inhibition) from having a visually similar preview available in parafoveal vision than from having a visually dissimilar preview available.

A partial replication of Balota et al.'s (1985) study was carried out recently by Drieghe, Rayner and Pollatsek (2005, experiment 1) who also employed the eye-tracking methodology. The main differences between the two studies is that Drieghe et al. only changed the penultimate letter of the target words (Balota et al. altered the final two letters) to produce the visually similar previews. This was done in order to achieve greater visual similarity between the target-previews and target-words. Drieghe et al. employed sentence frames such as (3) below.

(3) 'The doctor told Fred that his drinking would damage his _____ very quickly'.

In the experiment, the target word was always the predictable word[5] (e.g. 'liver' in the sentence above) and employed the following six parafoveal previews: Identical (e.g. 'liver'), unpredictable (e.g. 'heart'), semantically anomalous (e.g. 'files'), visually

[5] Thus meaning that here were no analyses relating to the interaction of preview-type with target predictability.

similar (e.g. ‘livor’), visually dissimilar (e.g. ‘heant’) and orthographically illegal (e.g. ‘frhos’). Drieghe et al.’s results revealed that single fixation durations[6] on the predictable target word were shorter following an identical preview than any of the other previews. The fact that fixation durations were shorter following the identical preview than following the visually similar preview, provides further evidence to suggest that parafoveal preview information is utilised during the processing of predictable words.

Overall, the research described above suggest that initial preview information is utilised during the processing of predictable and unpredictable words, and that the predictability effect is dependent upon the type of preview information initially available. Thus, it could be the case that in-line with the Guessing Game and Hypothesis Testing theories of reading, the predictability effect is due to a process of word-anticipation in which readers use contextual and parafoveal preview information to form a prediction about an up-coming word, and then either confirms or disconfirms this prediction during fixation of the word. One of the aims of Chapters 4, 5 and 6 of this thesis is to test this theory. Alternatively, it could be the case that the effect is driven by high-level contextual information which operates together with information at the level of the word to facilitate lexical access. This idea is further discussed in the subsequent section and is investigated experimentally in Chapter 8.

[6] Dissimilar to Balota et al., the authors did not employ the measure of gaze.

2.2.6. Are context effects best explained by a Modular or Interactive theory of language processing?

In the preceding section it was speculated that the predictability effect may be driven by high-level contextual information which is used in combination with low-level visual information to influence lexical access. If this hypothesis is correct, then the predictability effect may be best accounted for by an Interactive theory of language processing (e.g. McClelland, 1987). The Interactive theory suggests that both syntactic and contextual information influences activity in the lexical processor so that context effects can be the result of priming from the integrated sentence representation to individual words. However, it also predicts that context effects can be the result of intra-lexical priming (priming based on a fast and automatic activation that spreads via the connections between semantically related words).

An alternative hypothesis is that predictability exerts its influence at some post-access stage and that the effect arises from the integration of a word into the overall meaning of the sentence. This hypothesis is predicted by a Modular theory of language processing (e.g. Forster, 1979). According to this theory, language processing is autonomous, meaning that syntactic and contextual information from the sentence as a whole cannot be used to direct lexical access, although it can be used at a post-access integration stage. Additionally, this theory suggests that the only way that context can affect lexical access is via intra-lexical priming.

To date, a large number of studies employing naming tasks, lexical decision tasks and eye-tracking experiments have been undertaken with the aim of determining whether context effects are primarily due to intra-lexical priming or whether they predominantly arise at the discourse level. Evidence for intra-lexical priming effects by themselves cannot help discriminate between the Modular and Interactive theories but if there were no evidence for these, and there was evidence to suggest that context exerts its effect at the level of lexical access, this would provide evidence for an Interactive theory of language processing. In the majority of the studies which have examined this issue, *context effects* are not predictability effects per se. Of course this raises the question of “*what are context effects* ?” or “*what is context* ?”. “Context” seems to be an umbrella term which includes predictability and also plausibility. The idea of plausibility effects and the interest in them is fairly new (these are discussed in-depth in section *2.3*). Indeed it has only been in recent years that researchers have started to make distinctions between different types of context effects, clearly as the research in this area has advanced, there has become a need to make these distinctions.

Morris (1994) was one of the earliest researchers who tried to distinguish between the Modular and Interactive theories by using the eye-tracking methodology. Morris carried out two eye-tracking experiments, the first experiment provided evidence of intra-lexical priming effects: First fixation and gaze duration on a target noun were found to be significantly shorter when the target was embedded in a sentence which contained a subject noun and a verb that was related to the target (see 4a), than when the target was embedded in a sentence in which either the subject noun was neutral (4b), the verb was neutral (4c) or both the subject noun and verb were neutral (4d).

(4a) “The barber trimmed the *mustache* this morning”.

(4b) “The person trimmed the *mustache* this morning”.

(4c) “The barber saw the *mustache* this morning”.

(4d) “The person saw the *mustache* this morning”.

In Morris's (1994) second experiment, she found that the word 'mustache' was read faster when it was embedded in a sentence in which the nouns were semantically related to the target (see 5a) than when they were neutral (5b). However, this facilitation was not obtained when the nouns were embedded in a sentence in which the nouns were either semantically unrelated to the target word (5c) or were neutral (5d). This suggests that the obtained facilitatory effect was driven by the global meaning of the sentence rather than due to the lexical associations between the words in the sentence. Additionally, the direction and magnitude of the facilitatory effect did not differ between first fixation and gaze durations, leading Morris to conclude that context effects at the level of discourse, influence lexical access. Thus, if it is assumed that first fixation durations capture lexical access, then Morris's second study provides evidence for an interactive theory of language processing.

(5a) "The gardener talked as the barber trimmed the *mustache* after lunch".

(5b) "The friend talked as the person trimmed the *mustache* after lunch".

(5c) "The gardener talked to the barber and trimmed the *mustache* after lunch".

(5d) "The friend talked to the person and trimmed the *mustache* after lunch".

A more recent study which addresses the Interactive/Modular debate, is that by Pynte, New and Kennedy (2008) which investigated whether context effects arise primarily due to semantic properties of the immediate prior word or semantic properties of the prior sentence fragment. Using the French eye-movement data from the Dundee corpus, Pynte et al. carried out a series of multiple-regression analyses in which word Latent Semantic Analysis (LSA) and sentence LSA predictors were added into a baseline model which already contained a set of predictors known to influence fixation durations. Pynte et al. found that the fit of the model for both the single fixation and gaze duration analyses improved with the inclusion of the word LSA scores. The specific effects they found were that single fixation and gaze durations on a given target word decreased as its semantic relatedness to the prior word increased. Furthermore, and interestingly, the word-level semantic relatedness of the target word also exerted a backward influence on gaze durations on the prior word, thus providing evidence of a parafoveal-on-foveal effect. With regard to the sentence LSA scores, these were found to only significantly improve the fit of the model for gaze durations. The authors found that gaze durations on the target word decreased as the sentence LSA score associated with the target word increased. Thus, Pynte et al. found that local inter-word associations were responsible for early context effects, while more global effects of context exerted its influence at a post-lexical integration level, an outcome which is consistent with a modular theory of language processing.

Although many studies have set out to determine whether the language processor operates in a modular or an interactive manner, the debate remains unresolved. This issue will be further addressed in the section regarding plausibility effects (*2.3*) and is addressed experimentally in Chapter 8 of this thesis.

2.2.7. Other possible determinants of the word-predictability effect (Co-occurrence probability and Transitional probability)

Earlier in this chapter, evidence for whether surprisal contributes towards the predictability effect was presented. Recently, a number of researchers have investigated whether other factors, such as co-occurrence probability and transitional probability can capture some of the information in word predictability. Ong and

Kliegl (2008) have proposed that conditional co-occurrence probability (the probability that a word occurs given that the preceding word occurs in the context) may be a determinant of the predictability effect. These authors calculated co-occurrence probability (CCP) using a collection of data from the internet. Specifically, they took a collection of articles and counted how many times a pre-defined target word and preceding context word occurred together, then divided this by the total number of articles containing the context word. Ong and Kliegl then plotted the relationship between conditional co-occurrence and cloze predictability for words in the Potsdam sentence corpus and obtained a correlation coefficient of 0.5. Thus, CCP only appeared to capture a small part of the information in word predictability. Ong and Kliegl (2008) also added co-occurrence probabilities to the list of predictors used in a multiple-regression analysis to explain single fixation durations and gaze durations on a number of current and neighbouring words from the Potsdam sentence corpus. The authors found that the inclusion of the CCP predictor only caused a slight improvement in the fit of the single fixation and gaze duration models and that it did not significantly change the main effects of the predictability predictors in the models. That is, CCP does not seem to be part of the information contained within word predictability, or the CCP predictor would have affected the predictability predictor. Indeed, the authors showed that CCP acted more like word frequency in predicting fixation durations since it caused a change in the main effects of the frequency predictors within the models.

An alternative possible determinant of the predictability effect may be Transitional Probability as proposed by McDonald and Shillcock (2003a, 2003b). It should be noted from the outset however, that these authors believe that Transitional Probability is in fact an alternative to traditional word-predictability. McDonald and Shillcock propose a Transitional Probability effect in which low-level statistical knowledge between adjacent words can affect eye movement behaviour. It is completely low-level since it doesn’t involve any “high-level” knowledge about the context of the sentence. The authors make a distinction between Forward Transitional Probability (FTP) and Backward Transitional Probability (BTP). The former refers to the predictability of a particular word based on what the immediately preceding word is, while the latter refers to the predictability of a particular word based on what the immediately following word is.

In their first article which investigated transitional probability, McDonald and Shillcock (2003a) provide data relating to FTP effects. The authors selected 48 verbs which when followed by a noun created a high transitional probability between the word-pair and when followed by a different noun, created a low transitional probability between the word-pair. Participants were therefore presented with sentences in which the verb-noun pair was either of high (6a) or low (6b) transitional probability, while the context of the sentence was held constant. For example, participants could either be presented with:

(6a) “One way to *avoid confusion* is to make the changes during vacation”.

(6b) “One way to *avoid discovery* is to make the changes during vacation”.

McDonald and Shillcock’s results revealed that first fixation durations on the target noun were on average 11ms shorter when the verb-noun combination was of high transitional probability than of low transitional probability and that this effect was more pronounced as launch distance from the verb to the noun decreased, suggesting that visual information is required in order to obtain a FTP effect. In a subsequent article, McDonald and Shillcock (2003b) carried out a set of multiple regression analyses on corpus data in order to determine if transitional probability was a significant independent predictor of reading behaviour when effects of other factors, including predictability, were held constant. They found that FTP was a significant predictor of first fixation and gaze durations and that the direction of the effects was the same as that obtained in McDonald and Shillcock (2003a). That is, processing time on the noun was shorter when the verb-noun pair was of high transitional probability. McDonald and Shillcock (2003b) further showed that Backward Transitional Predictability was a significant predictor of first fixation durations and gaze durations. For example, first fixation and gaze durations were shorter on the word ‘arouse’ when the up-coming word was ‘suspicion’ (these words have a high transitional probability) than when ‘arouse’ preceded ‘hostility’ (these words have a low transitional probability). The authors also found that the size of the BTP effect was dependent on the eccentricity (visibility) of the up-coming (conditioning) word: The BTP effect was more pronounced when the final fixation on word n was four or less characters away from the conditioning word $n + 1$. The fact that the FTP and BTP effects were partly dependent on parafoveal preview information suggests that these effects involve bottom-up processing, thus further substantiating the claim that transitional probability is a low-level influence.

More recently, Frisson, Rayner and Pickering (2005) carried out two experiments which examined whether TP effects are independent from predictability effects. Their first experiment employed the same verb-noun pairs used in McDonald and Shillcock (2003a), but this time they were placed in either neutral or highly constraining sentences. The results indicated that there was no effect of BTP on first fixation, single fixation or gaze duration and no effect of FTP on first fixation or single fixation duration. However, there was a significant effect of FTP on gaze duration: On average, the critical noun was read 16ms faster when it was part of a high transitional probability verb-noun pair as opposed to a low transitional probability verb-noun pair. The authors point out that since they found a FTP effect in the measure of gaze but not in the measure of first fixation duration as found in McDonald and Shillock (2003a, 2003b) then it is unlikely that TP effects arise due to visual information available in the parafovea. Crucially however, the FTP effect they obtained did not interact with the context effect they also obtained, indicating that TP effects operate independently of predictability effects. However, in Frisson et al.'s experiment, the average predictability ratings between the item sets varied substantially (the mean ratings were .22 and .06 for the Predictable High Transitional Probability items and the Predictable Low Transitional Probability items respectively, and the ratings for the Unpredictable High Transitional Probability and Unpredictable Low Transitional Probability items were .07 and .01 respectively) and analyses on item subsets suggested that TP effects were only present when the items were not matched for predictability. The authors therefore carried out a second experiment in which the predictability ratings for the item sets were better matched (they were .20 and .18 for the Predictable High Transitional Probability and the Predictable Low Transitional Probability items respectively, and .02 and .01 for the Unpredictable High Transitional Probability and Unpredictable Low Transitional Probability items respectively) and no significant BTP or FTP effects were obtained, while regular predictability effects were observed. Thus, the authors concluded that transitional probability effects may not form part of traditional predictability effects.

More research is clearly needed in order to determine whether a word's co-occurrence probability contributes towards the predictability effect and whether Transitional

Probability effects are distinct from or are part of traditional predictability effects. Clarification of this latter issue would be particularly helpful as if the TP effect is part of the predictability effect, then this suggests that the predictability effect is driven in part by low-level statistical knowledge.

2.3. Plausibility effects

Plausibility refers to the likelihood of the event being described in a sentence, actually being true. The plausibility of a sentence is usually determined via a task in which a group of participants are asked to indicate on a likert scale, the likelihood of the event being described in a sentence actually being true. In the sentence “Lisa bought black shoes from the shop”, for example, the likelihood of a girl called Lisa buying black shoes from a shop is quite high, meaning that this sentence would probably be rated as being highly plausible. However, in the sentence “Lisa smoked black shoes from the shop”, the likelihood of a girl smoking shoes is very low, implying that this sentence would probably be rated as being very implausible.

The plausibility of a sentence affects sentence parsing, with sentence parsing taking longer the more implausible the sentence. There is current debate however, regarding the stage in the parsing process that plausibility has an effect on. Some studies have shown that plausibility is used immediately in the parsing decision process (e.g. Ni, Crain, & Shankweiler, 1996; Trueswell, Tanenhaus, & Garnsey, 1994), while others have shown that it is used during later re-analysis (e.g. Clifton, 1993; Clifton, Traxler, Mohamed, Williams, Morris, & Rayner, 2003; Ferreira & Clifton, 1986; Rayner, Carlson, & Frazier, 1983). A number of recent studies have investigated how early plausibility information is used by measuring eye-movements on a defined critical word. For example, Rayner, Warren, Juhasz and Liversedge (2004) tracked readers' eye-movements as they read sentences in which a defined target word (e.g. 'carrots' in the examples below) was either (7a) plausible, (7b) implausible or (7c) anomalous depending upon the preceding sentence context.

(7a) "John used a knife to chop the large *carrots* for dinner."

(7b) "John used an axe to chop the large *carrots* for dinner."

(7c) "John used a pump to inflate the large *carrots* for dinner."

The results of Rayner et al.'s (2004) study revealed that there was no significant difference between the plausible and implausible conditions in any of the inspection time measures taken on the target word. However, go-past durations and total reading times on the post-target region were significantly longer in the implausible condition than in the plausible condition, implying that plausibility exerts a late effect on eye-movement control. However, gaze durations, go-past durations and total reading times on the target word were significantly longer in the anomalous condition than in both the plausible and implausible conditions, implying that more severe implausibility, i.e. anomaly, exerts an earlier effect. Indeed, Rayner et al.'s results also revealed that gaze durations on the pre-target region (e.g. "the large", in the examples above) were also significantly longer in the anomalous condition than in either the plausible or implausible conditions. This latter outcome implies that a very early (parafoveal-on-foveal effect) was obtained when the up-coming word was severely implausible, although the authors claim that the effect was due to a small proportion of mislocated fixations.

A subsequent study by Warren and McConnell (2007) which was discussed in Chapter 1 (section *1.4.11*) showed that dissimilar to Rayner et al.'s (2004) study, the plausibility of a critical word can in fact influence processing strategy on the critical word, although the effects were apparent in later measures of processing time taken on the critical word. Similarly to Rayner et al.'s study (2004), however, severe implausibility, or anomaly, exerted an earlier influence on inspection strategy. The locus of these two types of effect are informative about the nature of plausibility effects, thus the implications of each will be discussed in turn.

The fact that the plausibility of a target word exerts a late effect on processing strategy of that word (when implausibility is not severe), implies that plausibility may exert its effect during a post-access stage and therefore may be caused by difficulty in integrating the implausible target word with the overall meaning of the sentence. Further evidence for this idea comes from a recent study by Warren and Patson (2010). These authors tracked readers' eye-movements as they read sentences which were either (8a) plausible or implausible (8b) and (8c). Additionally, the local propositions within the implausible sentences were either thematically related to the target word ('infant') as in (8b) or were non-thematically related (8c). The results indicated that inspection time on the critical word was not influenced by whether the local proposition and critical word were thematically related or not, while there was an overall effect of sentence plausibility, with longer critical-word inspection times for both types of implausible sentences.

(8a) "Bryan used a bottle to feed the hungry *infant* yesterday morning."

(8b) "Bryan used a bottle to fight off the hungry *infant* yesterday morning."

(8c) "Bryan used a trough to feed the hungry *infant* yesterday morning."

Warren and Patson's study appears to provide good evidence for a Modular account of language processing since effects of plausibility occurred late in the eye-movement record *and* did not appear to be due to intra-lexical priming. However, there are examples of other studies in the literature (e.g. Murray, 2005) which also provide evidence to suggest that plausibility effects are not due to intra-lexical priming yet some of these effects are obtained prior to the up-coming critical region. Murray (2005), for example, tracked readers' eye-movements as they read sentences via a delayed same/different sentence matching task. In the task, participants were presented with a sentence on a computer screen, and instructed to press a button to indicate when they had finished reading it. A second sentence then appeared directly below the first, and participants had to press a button to indicate whether the second sentence was the same as the first. Murray employed the following sentences: (9a) the relationship between the initial noun phrase and (up-coming) verb was plausible and the relationship between the second noun phrase and (preceding) verb was plausible, (9b), the relationship between the initial noun phrase and verb was plausible while the relationship between the second noun phrase and verb was implausible. Sentences (9c) and (9d) were identical except that the initial noun was changed to one which was an implausible subject of the verb.

(9a) "The lecturer with blonde hair delivered the packages".

(9b) "The lecturer with blonde hair delivered the cottages".

(9c) "The princess with blonde hair delivered the packages".

(9d) "The princess with blonde hair delivered the cottages".

Murray showed that go-past durations on the second noun phrase were longer when this phrase was implausible (9b) and (9d) than when it was plausible (9a) and (9c), a finding which may be attributed to post-lexical integration of the meaning of the critical region to the overall meaning of the preceding sentence. However, when the initial noun phrase was an implausible subject of the verb (9c) and (9d), go-past durations were also longer in the region which comprised the prepositional phrase (i.e. “with blonde hair”). Thus, a very early effect of plausibility was obtained given that the verb was at this point as-yet-unfixated. Additionally, the nature of the initial noun phrase continued to exert an effect on the verb and determiner (i.e. “delivered the”). Taken together, these latter outcomes imply that the plausibility effect was emerging over time, and this effect was unlikely to be due to intra-lexical priming since the initial noun phrase and verb were separated by a prepositional phrase. Thus, the results are difficult to reconcile with a Modular account of language processing. However, the early plausibility effects were also unlikely to be due to an effect of context at the discourse level. This is because, the same effects were obtained when the same sentence was presented a second time. That is, if the effects arose due to a difficulty with constructing a discourse model, then it is unlikely that the system would experience this twice. Thus, Murray’s outcomes are also difficult to reconcile with an Interactive account.

Since Murray (2005) showed that plausibility effects cannot be easily accounted for by either Modular or Interactive theories led him to propose that plausibility effects may instead be the result of an incremental interpretive process. This type of process may therefore account for early effects of severe implausibility, and theoretically, could also be the mechanism underpinning the predictability effect.

2.4. Word-frequency effects

Word frequency is a term used to refer to how often a word is used in written language. As discussed in Chapter 1, in the reading literature, a distinction is made between high- and low-frequency words. Word frequencies are determined by way of databases such as the Kuçera-Francis written frequency count (Kuçera & Francis, 1967) and the CELEX English word form corpus (Baayen, Piepenbrock & Gulikers, 1995). It is well-known that the frequency of a word affects how long it takes to process the word. Indeed, out of all the variables that affect processing time on a word, word frequency seems to be the most influential variable (Whaley, 1978) and one of the most robust findings in the literature is that high-frequency words are processed faster than low-frequency words. This word frequency effect was first found in tasks measuring lexical processing, e.g. lexical decision and naming tasks (Besner & McCann, 1987; Forster & Chambers, 1973; Frederiksen & Kroll, 1976; Hudson & Bergman, 1985; McCusker, 1977; Monsell, Doyle & Haggard, 1989; Norris, 1984; Paap, McDonald, Schvaneveldt & Noel, 1987; Scarborough, Cortese & Scarborough, 1977; Stanners, Jastrzembski & Westbrook, 1975; Whaley, 1978), semantic categorization tasks (Forster & Shen, 1996; Monsell et al., 1989) and in tasks that measure visual duration thresholds (Howes & Solomon, 1951).

With regard to eye movements in reading, the frequency of a word primarily affects the temporal aspect of eye-movement control: First fixation durations, gaze durations and single fixation durations are all longer for low-frequency words than for high-frequency words (Altarriba, et al., 1996; Henderson & Ferreira, 1990;1993; Hyönä & Olson, 1995; Inhoff & Rayner, 1986; Just & Carpenter, 1980; Kennison & Clifton, 1995; Raney & Rayner, 1995; Rayner, 1977; Rayner & Duffy, 1986; Rayner &

Fischer, 1996; Rayner & Raney, 1996; Rayner, Sereno & Raney, 1996; Rayner, Fischer & Pollatsek, 1998; Vitu, 1991). The prevailing theory in the literature is that these effects arise because more frequent words are accessed from the lexicon faster than less frequent words, although there are a few (e.g. Balota, 1990) who argue that the effect arises at the post-access level.

There is also a “spillover effect” from fixating low-frequency words with fixation time on the following word being inflated (Rayner & Duffy, 1986). Moreover, there is evidence in the literature of a spillover effect from fixating either a high- or low-frequency word (although the effect is more pronounced when the word is short and of low-frequency) with the effect being evident in up to two fixations of the following word and being directed towards subsequent words (McCullough, 2001). Thus, while a word’s frequency can exert a very early influence on word-encoding time, it can also exert a very late effect.

It should be recalled from Chapter 1, that high-frequency words are far more likely to be skipped than low-frequency words and that low-frequency words are more likely to be refixated than high-frequency words. Additionally, more parafoveal preview benefit is obtained from a high-frequency parafoveal word than from a low-frequency parafoveal word (Inhoff & Rayner, 1986) and parafoveal preview benefit is greater when the currently fixated foveal word is a high-frequency word (Henderson & Ferreira, 1990; Schroyens, et al., 1999; Kennison & Clifton, 1995).

2.5. Do word-frequency and word-predictability exert additive or interactive effects on word-processing time?

A current debate in the literature is whether word-frequency and word-predictability exert additive or interactive effects on word-processing time. This topic is of significance as it bears on the issue of whether frequency and predictability affect the same stage of word encoding: Using Additive Factors logic (Sternberg, 1969), an interaction would indicate that the variables affect the same stage of word encoding whereas no interaction may indicate that they influence different stages. However, Rayner, et al. (2004) point out that it is difficult to apply Additive Factors logic to fixation durations since fixation durations cannot be directly related to lexical access. Sternberg's Additive Factors logic was originally applied to reaction time measures and the logic assumes that reaction time represents the total processing time of a stimulus, while fixation time measures do not assume this as lexical access is distributed. Nevertheless, if frequency and predictability were shown to interact, this would be a good indicator that the variables affect the same stage of word-encoding. Thus, determining whether the two variables interact or not will aid understanding of the time-frame in which word-predictability operates, as well as the nature of the effect.

Early reaction time studies (e.g. West & Stanovich, 1982; Becker, 1979) and pronunciation tasks (e.g. Stanovich & West, 1979, 1983) suggested that frequency and predictability do interact. All of these early studies showed that there was more contextual facilitation for low-frequency words than for high-frequency words. Given that frequency effects are widely considered as being effects relating to lexical access (although c.f. Balota, 1990), these studies therefore imply that predictability may also be a lexical access effect. However, the conclusions from these early studies can only be tentatively drawn. This is because, in reaction time studies, there is a delay between when the prior context is presented and when the target word appears, meaning that these studies are not able to capture moment to moment cognitive processing.

A number of recent eye-tracking studies (e.g. Rayner et al., 2004; Altarriba et al., 1996; Lavigne et al., 2000; Rayner et al., 2001; Ashby, Rayner & Clifton, 2005; Kennedy, Pynte, Murray & Paul, submitted), which provide an on-line measure of moment to moment cognitive processing, have re-examined the additive/interactive issue. These studies have shown that word-frequency and word-predictability do not interact. In the experiment by Rayner et al. (2004) for example, participants' eye-movements were recorded as they read sentences in which a defined target word (which could either be of high- or low-frequency and predictable or unpredictable) was embedded. Specifically, the materials were designed in such a manner so that each of the sentences served as the context for two possible target words (a high-frequency or a low-frequency word). The sentence in which a high-frequency word was predictable was the same context in which a low-frequency word was unpredictable. Thus in (10a), the high-frequency predictable word 'bottle' or the low-frequency unpredictable word 'diaper' could fit into the sentence. Each pair of words also appeared in a second (paired) sentence in which the low-frequency word was the predictable word and the high-frequency word was the unpredictable word. Thus in (10b), the low-frequency predictable word 'diaper' or the high-frequency unpredictable word 'bottle' could fit into the sentence.

(10a) “ Before warming the milk, the babysitter took the infant’s _____ out of the travel bag”.

(10b) “To prevent a mess, the caregiver checked the baby’s _____ before leaving”.

The results of Rayner et al.’s (2004) study revealed that frequency and predictability did not interact in either first-fixation duration, single-fixation duration or gaze duration, although there were main effects of both frequency and predictability. A similar outcome was subsequently obtained by Ashby et al. (2005). Using the same materials employed by Rayner, et al. (2001, experiment 2; Rayner, et al., 2004), Ashby, et al. (2005) carried out an eye-tracking experiment which investigated whether the type of frequency and predictability effects obtained were dependent on reading ability. In the study, two groups of readers were employed. Using the Nelson-Denny Reading test, the first group was identified as being highly-skilled readers as they scored above the 74th percentile on the reading test and the second group consisted of average readers (mean score = 40th percentile). Ashby et al. found that target-frequency and predictability combined additively on first fixations, single fixations and gaze durations for both the highly skilled and average reader group data.

There are however, a number of problematic aspects with the experimental materials employed by Rayner et al. (2004; Rayner et al., experiment 2, 2001; Ashby et al., 2005). Indeed it is questionable whether the materials were ~~adequa~~te for use in an eye-tracking study. First, the two target words which each sentence fragment predicts are not matched for length in 3 of the 32 sentences. To take the example of the following sentence used in the study, “Bugs Bunny eats lots of   to stay healthy ”, the two target words were ‘carrots’ and ‘potatoes’. Although word length only differs by one character, it is clear that differences in eye movements between participants who read 'carrots' and participants who read 'potatoes' could be due to the fact that these two words differ in length. Second, the word prior to the target word in each sentence is part of the "critical region" of the sentence, therefore it is important to control this word also. However, this word was not controlled for frequency or for length. There were cases when the word prior to the target word was very long (e.g. 11 characters) or very short (i.e. 1 character). Even more critically, the word prior to the target word in some of the sentence pairs was not matched for length either. For example, in the sentence, "He planned to refinish the hardwood floor…", the pre-target word 'hardwood' is 8 characters long, but in the paired sentence, "The librarian returned the books to the appropriate floor…", the pre-target word 'appropriate' is 11 characters long. Obviously, any differences in eye movements between these two sentences could be due to differences in the length of the word prior to the target word (e.g. causing a variation in launch position). Finally, some of the sentences are implausible. For example, the sentence "John stirred the hot soup with the broken plate until it was ready to eat" does not sound plausible at all. Since the design of the experimental items meant that two different words had to be predicted by each sentence, the two forms of each sentence may obviously differ in plausibility[7], but this does not necessarily mean that relatively plausible sentences were impossible to achieve.

A recent eye-tracking study by Hand, Miellet, O'Donnell and Sereno (2006) suggests that frequency and predictability do interact when the experimental materials and launch position into the target word are controlled. Using the same design (but improved materials) employed by Rayner et al. (2004; Rayner et al., experiment 2,

[7] Ashby et al. (2005) do in fact acknowledge that the sentences which contained an unpredictable target word were atypical, however, the authors maintain that these sentences were still quite plausible.

2001; Ashby et al., 2005), Hand et al. found that when the eyes were between 1-3 characters away from the target word, contextual constraint facilitated low-frequency words, but not high-frequency words, whilst the opposite was true at launch sites of 4-6 characters from the target word. There was no interaction at more distant launch sites, leading the authors to conclude that joint effects of frequency and predictability are modulated by the amount of preview information initially available.

There is also evidence from ERP work which suggests that frequency and predictability interact during the early stages of word processing. In an ERP study by Sereno, Brewer and O'Donnell (2003), frequency and predictability were found to interact in the N1 component from 132 – 192ms (an early window in which lexical access is known to occur and word-frequency effects have been found), (although c.f. Dambacher, Kliegl, Hofmann & Jacobs, 2006). Specifically, there was more (albeit non-significantly) facilitation for low-frequency words, an outcome which is compatible with the early reaction time studies.

As well as clarifying the time-frame of frequency and predictability effects, resolution of the nature of the relationship between the variables is important for modeling purposes. It should be recalled from Chapter 1, that in the earlier versions of the *E-Z Reader* model (e.g. Reichle, Pollatsek, Fisher & Rayner, 1998), frequency and predictability interacted, but in response to the eye movement studies (discussed above) which suggested that the two variables exert additive effects on fixation durations, the *E-Z Reader* model was modified (Pollatsek, Reichle & Rayner, 2006c) so that the time needed to identify a word is now an additive function of its frequency and predictability. Using Additive Factors logic, an interaction would imply that the variables affect the same stage of processing, however, additive effects do not necessarily imply that the variables affect different stages. That is, it is possible that the variables affect the same stage but do not interact with each other. This means that since the *E-Z Reader* model proposes that frequency and predictability both affect the same stages of word encoding, the variables could plausibly combine either additively or multiplicatively within the model. Thus, whether the variables interact or not is not critical to the architecture of the model, but it is important that models can account for the data and Pollatsek et al. may have been rather hasty in changing the predictions of the model if it is the case that frequency and predictability interact when the experimental stimuli are adequately controlled and when launch position into the critical word is controlled. Experiments 4 and 5 of this thesis set out to address this issue.

2.6. Are words processed in serial or in parallel?

As discussed in Chapter 1, a current on-going debate in the field of reading research is whether words are processed in a strict serial-sequential manner or whether distributed processing occurs during reading. Until fairly recently, the general view was that words are processed serially and this is the fundamental assumption of the *E-Z Reader* model which at present, is arguably the most influential model of reading within the domain of eye-movement control. However, a vast number of studies have reported evidence of parafoveal-on-foveal effects which go against the concept of strict serial processing in reading. Parafoveal-on-foveal effects relating to both the temporal and spatial aspects of eye-movement control have been reported in the literature. That is, properties of an as-yet-unfixated (parafoveal) word have been shown to affect fixation durations on a currently fixated foveal word and where this word is first fixated.

The first documented accounts of parafoveal-on-foveal effects were reported by Kennedy (1995; 1998). In Kennedy's experiments, participants viewed a fixation marker on a screen after which, three words were presented on the screen. The first word was either the word 'looks' or the word 'means'. In the 'looks' case, participants had to indicate (by pressing a button on a button-box) whether the two following words had the same spelling. In the 'means' case, participants had to indicate whether they had the same meaning. The main findings in both studies were that gaze duration on a foveal word showed a sensitivity to the length, frequency and initial–letter constraint ("informativeness"[8]) of the as-yet-unfixated parafoveal word.

Parafoveal-on-foveal effects have since been shown in a number of subsequent studies. For example, there is evidence in the literature of parafoveal-on-foveal timing effects arising from predictability and sentence plausibility (see sections *2.2.4* and *2.3* respectively). Additionally, the frequency of a word in parafoveal vision is known to affect processing time on a currently fixated word (e.g. Kennedy & Pynte, 2005; Pynte & Kennedy, 2006; Kennedy, Pynte & Ducrot, 2002; Kennedy, 2000a, 2000b; Underwood, Binns & Walker, 2000), but only when the foveal word is short so that enough of the upcoming word can be identified while in parafoveal vision (Kennedy et al., 2002; Kennedy & Pynte, 2005). In these cases, the parafoveal-on-foveal frequency effect is in the orthodox direction, with processing time on the foveal word increasing when a low-frequency word is present in parafoveal vision. When the foveal word is long, lexical frequency of the parafoveal word does not affect foveal processing since not enough of the parafoveal word is visible. Instead, only the initial

[8] Informativeness (or type frequency) refers to the number of different words of the same length consistent with the initial letters of the word in question. Thus an informative word is one which shares its initial three letters with very few words.

familiarity[9] or informativeness of the parafoveal word exert an effect on foveal processing, especially if the parafoveal word is also long (e.g. Pynte & Kennedy, 2006; Kennedy & Pynte, 2005; Kennedy, et al., 2002; Kennedy, 1998).

The studies which have examined parafoveal-on-foveal effects of familiarity (e.g. Pynte & Kennedy, 2006; Pynte, Kennedy & Ducrot, 2004) and informativeness (e.g. Kennedy, 1995; Kennedy, 1998; Inhoff, Starr & Shindler, 2000b; Underwood, et al., 2000; Kennedy, 2000, 2000b; Kennedy, et al., 2002; Kennedy & Pynte, 2005; Pynte & Kennedy, 2006) have shown inconsistencies in the direction of results reported. For example, foveal processing may either increase or decrease depending on whether the parafoveal word is informative or uninformative. However, Kennedy et al. (2002) suggest that these inconsistencies relate to a failure to adequately control foveal and parafoveal word lengths.

In the literature, there is also evidence of "long-range" parafoveal effects. For example, in an eye-tracking study by Kliegl, Risse and Laubrock (2007) in which participants read sentences for comprehension, the preview of words *n*, *n* + 1 and *n* + 2 were manipulated so that they were either identical to the actual word or were a random letter-string (which was the same length and shape as whatever the actual word was). When the identical (unchanged) preview of *n* + 2 was available (and when the unchanged preview of *n* + 1 was available), gaze duration on a currently fixated word (*n*) was significantly shorter than when the non-word preview of *n* + 2 was presented. Thus there were significant effects on *n* stemming from the preview of word *n* + 2 (although Rayner, Juhasz and Brown, 2007, did not find this effect in a similar experiment). Further evidence of "long-range" parafoveal-on-foveal effects

[9] Familiarity (or token frequency) refers to the cumulative lexical frequency of all words of the same length sharing the initial three letters of the word in question (thus an orthographically familiar word is one which shares its initial three letters with a large number of other words).

comes from a study by Kennedy, Murray and Boissiere (2004). Kennedy et al. (2004) provide evidence to suggest that the orthographic properties of a word, when present in a short sentence in a single line, can affect previous inspection times as far as 15.2 characters ‘downstream’.

With respect to parafoveal-on-foveal *where*? effects, a number of recent studies have also provided evidence of these effects occurring at both lexical and sub-lexical levels. As previously discussed, Lavigne, et al. (2000) have reported evidence of right-shifted landing positions on predictable words, although the balance of evidence suggests that word predictability does not affect where words are first fixated (Rayner, et al., 2001; Vonk, et al., 2000). There is also evidence to suggest that whether an up-coming word is a content or a function word can determine where current words are fixated. For example, in the study by Kliegl, et al., (2007), discussed above, fixations on word *n* were closer to word *n* + 1 when *n* + 1 was a function word than when it was a content word, and this was true when word length was controlled. With regard to sub-lexical effects, morphology (Inhoff, Briihl & Schwartz, 1996; Hyönä & Pollatsek, 1998) and orthographic familiarity can also influence where words are first fixated (e.g. Pynte & Kennedy, 2006; White & Liversedge, 2004; Pynte et al., 2004; Radach, Inhoff & Heller, 2004; Vonk, et al., 2000; Beauvillain & Doré, 1998; Doré & Beauvillain, 1997; Beauvillain, Doré & Baudouin, 1996; Hyönä, 1995).

Most early evidence (e.g. Carpenter & Just, 1983; Henderson & Ferreira, 1993) suggested that properties of a word in parafoveal vision did not affect processing of a currently fixated word. A number of recent studies have also failed to find any evidence of parafoveal-on-foveal timing effects (e.g. one condition in an experiment by Schroyens, et al., 1999; experiment 1 of Pynte et al.'s study, 2004; White & Liversedge, 2004; Rayner, et al., 2003; Rayner et al., 2007). However, there is now a vast amount of literature to suggest that both parafoveal-on-foveal timing effects and parafoveal-on-foveal *where* effects are psychologically real. As discussed in Chapter 1, the *E-Z Reader* model has been modified so that low-level parallel processing is predicted to occur across a whole page of text. This means that the model can now account for parafoveal-on-foveal effects relating to orthographic properties of up-coming words. However, proponents of the serial viewpoint persist that high-level parafoveal-on-foveal timing effects do not exist and that the effects are instead, the result of mislocated fixations. However, it seems implausible that the effects arise due to mislocated fixations (see previous chapter for arguments) and more plausible that words are sometimes processed in parallel. Nevertheless, given that the direction and nature of parafoveal-on-foveal effects do seem to vary between studies, more research is clearly needed in order to provide evidence of systematic parafoveal-on-foveal effects.

Chapter 3:

Methodological issues relating to measures of processing time employed in this thesis

3.1. Is there a tight coupling between eye and mind?

In the field of psycholinguistics, a central aim is to understand the time course of the influence of a linguistic variable on readers' processing of text. The most common method of achieving this, is to conduct experiments in which readers' eye movements are recorded as they read text on a computer screen. How long it takes an individual to read different regions of the text is computed and this information is utilised in order to draw inferences about the influence of linguistic variables on word-processing time. This methodology assumes that there is a tight coupling between eye-movements and the underlying cognitive processes and this is precisely what is argued in the 'immediacy hypothesis' (Just & Carpenter, 1980). Specifically, Just and Carpenter proposed that readers try to interpret each word as it is encountered and that the eyes remain fixated on a word as long as the word is being processed. There is some support for this view, given that abundant evidence was presented in the previous chapter to suggest that the linguistic properties of text can have a direct influence on the time it takes to read that text. However, the literature also suggests that words can be processed without direct fixation. For example, it is widely accepted that an up-coming word can be parafoveally processed and that processing of *n* can continue while *n* + 1 is being fixated. In addition, there is evidence of distributed processing during reading. Thus, while it does not appear to be the case that the eyes move at their own pace with process monitoring intervening when necessary (Kolers, 1976), it also appears that the coupling between eye and mind might not be as tight as Just and Carpenter (1980) propose.

3.2. What is the best measure of processing time?

With the assumption that the linguistic properties of text do have a direct influence on the time taken to process that text, there is considerable debate regarding which is the best measure of processing time to use. This debate largely arises from the fact that there is not one single measure which can capture all of the processing events which occur during word-processing. Some words are fixated for longer periods than others, while some are skipped or are fixated more than once so clearly it would be difficult to capture all of these events with one measure. In addition, as discussed in section *3.1.* above, there is evidence to suggest that the cognitive processes that take place during word-processing can overlap, meaning that measuring the processing time on *n* is often not sufficient when trying to understand the full effect of the linguistic properties of *n*. Thus, in order to determine the temporal processing associated with a given word, it is usual for researchers to simultaneously employ more than one measure of processing time (and to examine processing time on the subsequent word). Two of the most frequently used indexes of cognitive processes are the first fixation duration and gaze duration on a word. These, as well as some of the other measures often employed in psycholinguistic research will be discussed and evaluated in the up-coming sections.

3.2.1. First fixation duration

In the field of psycholinguistics, the measure of first fixation duration was first used by Inhoff (1984). As the name implies, it is the mean duration of the first fixation on a word during first pass reading regardless of whether it is the only fixation or the first of many fixations on a word. First fixation duration is a very “early” measure of word-processing difficulty since it is the first time that a reader directly fixates a word. Indeed, first fixation duration is often assumed to reflect lexical access of a word, but this may only be the case if the first is the only fixation (and some researchers (e.g. Kliegl, 2007) have restricted analyses to this sub-set). However, since a word is often fixated more than once during the first sweep of the eyes, this means that a number of fixations can contribute to initial word-processing and that a measure which captures all of these fixations is needed.

3.2.2. Gaze duration

The measure of gaze duration has been used for many years in the field of vision research. It is generally assumed that the direction of gaze indicates what object is currently being processed and that gaze duration indicates object-identification time. In the field of psycholinguistics, gaze duration was first employed by Just and Carpenter (1978;1980) and is assumed to index word-identification time. Specifically, it is the summed duration of all fixations within the current pass before leaving the word to exit to the left or right and therefore does not include the time spent making inter-word regressions. Since gaze duration does not include inter-word regressions, it is considered to be a first pass measure of reading time. Indeed, Inhoff (1984) has shown that gaze duration often yields similar results to first fixation duration thus implying that gaze duration can capture early cognitive events. However, gaze does include intra-word regressions (re-fixations) and if these equal re-processing then it can be considered a relatively late measure (although it could be counter-argued that moving the eyes again does not necessarily reflect anything later than staying there and looking). Because of these issues, gaze is commonly referred to as a 'mid' measure of word-identification time.

Gaze duration is also assumed by researchers to indicate ease of processing since word-identification time is largely dependent on word-difficulty (gaze duration is predicted to increase as word difficulty increases). Thus, when encountering a difficult word, the typical response is to make a single long fixation or a number of successive fixations on the word. If the results of a controlled experiment reveal that the duration of the single fixation or the sum of the multiple fixations for a difficult word is longer than that for an easier counter-part, then the experimenter can assume that the measure of gaze duration has detected the effect. However, as Liversedge, Paterson and Pickering (1998) point out, there are at least two alternative responses to encountering a difficult word: An immediate regression can be made out of the word (re-reading earlier parts of the sentence may help the reader integrate the difficult word with the prior sentence content) or an immediate forward saccade can be made (reading the rest of the sentence can also help resolve processing difficulty). Both of these responses would result in a short gaze duration on a difficult word, meaning that there may be no difference in gaze duration between a difficult and an easy word in a controlled experiment. This is problematic as it means that gaze duration does not always produce an accurate reflection of ease of word-processing and could potentially lead to a distortion of experimental effects.

The measure of gaze duration is assumed to capture average word-identification time but how close it comes to doing this is also questionable. It has been discussed numerous times throughout this thesis that word-identification usually begins before a word is directly fixated, meaning that gaze duration will clearly not capture total word-identification time for *n.* In addition, parafoveal processing of *n* + 1 will be included in gaze duration for *n.* Thus, average gaze duration for *n* will not solely reflect mean identification difficulty of *n*. In order to remedy this problem, Rayner and Pollatsek (1987) have suggested that preview benefit of *n* + 1 should be added to the fixation time on *n* + 1 and be subtracted from the time spent fixating *n*. However, this proposal ignores the fact that time spent processing a word can sometimes spill-over onto the next word.

An alternative proposal is that the measure of gaze duration should include cases of zero gaze (i.e. cases where words have been skipped). Murray (2000) argues that mean gaze duration probably comes close to equating mean identification difficulty only when cases of zero gaze are included in the calculation of averages[1]. He suggests that average gaze duration (which does not include cases of zero gaze) for when *n* is inspected is an overestimate of identification time for *n* since it will include the time spent parafoveally processing *n* + 1. If cases of zero gaze are included, this

[1] The assignment of zero fixation duration to skipped words was proposed by Just and Carpenter (1978; 1980).

will reduce average gaze duration and the outcome will likely approximate mean word-identification time. There are some problematic aspects of this proposal however. First, it ignores the fact that, as previously discussed, some of the processing of *n* would have taken place parafoveally while the eyes were fixating *n* – 1 (meaning that word-identification time for *n* will not be extremely overestimated). Second, it is *actual* mean word-identification time which we wish to determine as opposed to some approximate time, however it seems unlikely that any gaze computation will ever manage to produce this, especially since there is the added problem of how to deal with spill-over effects. Perhaps the strongest argument against Murray's (2000) proposal is 'presentational', that is, average gaze duration is often shorter than average first fixation duration, which appears counter-intuitive.

A final source of controversy regarding the computation of gaze is whether it should include the time spent making saccades within a word and to the next word. Irwin (1998) argues that saccade time should be included since lexical processing continues during saccades. However, the general consensus is that saccade time should not be included: Intra-word saccades are fairly brief and re-fixations are not that common, suggesting that the inclusion of saccade time should not lead to significant changes in effect size, indeed, there is evidence by Blanchard (1985) to corroborate this.

3.2.3. Go-past duration

Often a number of inter-word regressions are made during reading, and a measure which can simultaneously capture the time spent making inter-word regressions from a word as well as gaze durations on the word is the combinative measure of go-past duration. Go-past duration, also (somewhat confusingly) referred to as Total Pass (Kennedy, Murray, Jennings & Reid, 1989; Murray, 2000), First Pass (Hill & Murray, 2000), Regression Path reading time (Konieczny, 1996), Regression Path (Konieczny & Hemforth, 2000; Van Gompel, Pickering & Traxler, 2000) and Cumulative Region reading time (Mitchell, Brysbaert, Grondelaers & Swanepoel, 2000), is formally defined as the summed duration of all fixations within the current pass before leaving the word to exit to the right. Since go-past duration includes the time spent making inter-word regressions and the time spent fixating a word following a regression, this means that this measure does not lose data. It therefore provides a more complete indication of the total time spent processing (although not necessarily looking at) a word than the measure of gaze duration does and is less likely to lead to a distortion of effects. However, the strength of this measure is also its weakness: Since it includes re-fixations and regressions, it is clearly not a ‘pure’ measure of first pass reading time. As discussed above, it is debatable whether including re-fixations constitutes first pass reading, thus the question of whether or not to include the time spent regressing out of a word in a measure of first pass reading is even more debatable.

3.2.4. Single-fixation duration

A measure which is sometimes used in replace of gaze duration is that of single-fixation duration. This measure computes average fixation duration on a word when the word has been fixated only once. Some argue (e.g. Kliegl, 2007) that single fixation duration is the purest measure of processing difficulty as it measures non-overlapping processes. However, this measure is highly controversial as it excludes instances in which a word receives more than one fixation and cases in which a word is first fixated following either a regressive saccade from the subsequent word or a regressive saccade to the prior word, meaning that it loses a significant amount of data. Specifically, the measure of single fixation duration does not represent the default eye-movement pattern when the word is very short or very long. This is because, short words tend to be skipped over more often while long words tend to be re-fixated more often meaning that data for these cases will be excluded from analysis. Similarly, high-frequency words tend to be skipped more often while low-frequency words tend to be re-fixated more often. Thus, it seems that employing the measure of single fixation duration may only be suitable for determining average fixation duration on words that are medium in length and in frequency. In order to get a full picture of the eye-movement behaviour on short and long and high- and low-frequency words, a first pass measure (such as gaze or go-past duration) is clearly needed in conjunction with the measure of single fixation duration.

3.2.5. Total reading time

The measure of total reading time sums all of the fixations made within a critical region or word as well as the fixation duration made on the word following a regression from the subsequent word. This latter fact means that the measure of total reading time is considered to be a relatively late measure of processing difficulty. If an effect is obtained for total reading time but not for measures such as first fixation duration, then this usually suggests that an experimental manipulation has exerted a late effect on word-processing.

3.3. Measures employed in this thesis

Eye-tracking methodology is employed in order to address the research questions of this thesis. Six key measures are taken in all of the experiments. The measure of first fixation duration is taken since this is crucial for capturing any early effects produced by the experimental manipulations. Despite the shortcomings associated with the use of gaze duration, it is seen as the 'industry standard' and is therefore also employed. The measure of gaze computed for use in this thesis includes cases of zero gaze since it has been argued that including these cases produces durations which come close to reflecting mean word-identification time. However, since gaze duration loses a lot of data, the measure of go-past is also utilised in this thesis. The measure of re-reading time is also employed. Re-reading time refers to the amount of time spent regressing and is the difference between gaze and go-past duration (since it includes both intra- and inter-word regressions). It is useful to employ this measure as it can clarify whether any differences between gaze and go-past duration data are due to the time spent regressing. Additionally, in order to capture any late effects produced by the experimental manipulations, the measure of total reading time is utilised. The final measure taken, which cannot be easily classified as either a fixation position or an inspection time measure, is that of skipping rate. Skipping rate reveals whether a word has been fixated or not and is a crucial measure to take when measuring predictability and frequency effects since predictable and high-frequency words are skipped over more often than unpredictable and low-frequency words

Chapter 4:

Do frequency and predictability exert interactive or additive effects on fixation durations?

4.1. Introduction

This study primarily aims to determine whether frequency and predictability exert additive or interactive effects on fixation durations, while a second aim is to investigate whether it is the case that readers use a combination of contextual and parafoveal preview information to form predictions about up-coming words.

The present experiment is an extended replication of a pilot study which was previously conducted in order to address the above theoretical issues. The materials and design which were employed here were constructed for the pilot study in which 24 participants took part. The pilot study was successful in that it revealed a number of marginally significant main effects and interactions which were theoretically informative. Thus, in order to adequately address the research questions it was necessary to re-run the experiment with a larger group of participants (32 were used here). None of the final 32 participants took part in the pilot study.

As discussed in Chapter 2, whether frequency and predictability exert additive or interactive effects on fixation durations bears on the question of whether word-frequency and word-predictability affect the same stage of word encoding. As Rayner, Ashby, Pollatsek and Reichle (2004) rightly point out, fixation durations do not directly relate to lexical access (since lexical access is distributed), meaning that it is difficult to apply Sternberg's (1969) Additive Factors logic to fixation durations. Nevertheless, if frequency and predictability were shown to interact, for example, then this would be a good indicator that the two variables affect the same stage of word-encoding. Thus, determining whether frequency and predictability interact or not, could reveal the time-frame of the predictability effect, which could in turn, help to reveal the nature of the effect. If frequency and predictability were found to interact in the measure of first fixation duration for example, then since word-frequency is assumed to be a lexical access effect (although c.f. Balota, 1990) and since first fixations are widely assumed to capture lexical access, then it may be possible to conclude that predictability exerts its effect at the level of lexical access. This conclusion might suggest that the predictability effect could be best accounted for by an Interactive account of language processing. If it were shown that frequency and predictability exert additive effects on fixation durations, then this might instead imply that the variables influence different stages, although it could equally be plausible that the variables influence the same stage but do not interact.

The architecture of the *E-Z Reader* model (e.g. Reichle, McConnell & Warren, 2009) currently assumes that frequency and predictability exert additive effects on fixation durations. However, the model does not predict that the variables influence different stages of word-encoding, instead, the variables are predicted to non-interact during both a very early stage (L_1) of word-processing as well as a later lexical access stage (L_2). In the SWIFT model, both frequency and predictability influence a lexical pre-processing stage. Dissimilarly to the E-Z Reader model, however, word-frequency and predictability are not combined in a single equation for word-difficulty, meaning that this model can currently handle either interactive or non-interactive effects. Thus, frequency and predictability are modelled differently in the two models.

Whether the variables interact is a source of controversy, this is because the data reported in the literature have been inconsistent. For example, a number of early studies employing lexical decision (e.g. Becker, 1979; Stanovich & West, 1981) and pronunciation (e.g. Stanovich & West, 1979; 1983) tasks provided evidence suggesting that predictability effects are larger for low-frequency words than for high-frequency words. However, a recent spate of eye-tracking experiments (e.g. Rayner, et al., 2004; Altarriba, Kroll, Sholl & Rayner, 1996; Lavigne, Vitu & d'Ydewalle, 2000; Rayner, Binder, Ashby & Pollatsek, 2001; Ashby, Rayner & Clifton, 2005; Kennedy, Pynte, Murray & Paul, submitted) have provided evidence of additive effects. It should be recalled from Chapter 1, that *E-Z Reader* originally assumed that the variables exerted interactive effects but based on the outcome of some of the eye-tracking studies cited above, the authors then changed the parameters of the model so that it now assumes additive instead of interactive effects.

The authors of *E-Z Reader* may have been rather hasty in changing the parameters of their model. This is because, and as previously discussed in Chapter 2, there are problematic aspects of the methodology used in at least three of the six eye-tracking studies which have reported additive effects. It will be recalled that in the experiments carried out by Rayner, et al. (2001, experiment 2; Rayner et al., 2004; Ashby, et al., 2005), the materials were designed in such a manner so that each of the experimental sentences served as the context for two possible target words while each pair of target words could also fit into a second (paired) sentence. However, target-word pairs were not controlled for length and the materials had a number of other short-comings (see section *2.5.*). One of the main deficiencies with their materials is that the length of the word prior to the target word was not controlled, thus potentially causing a variation in launch position. If there were variations in launch positions, then there would have been variations in target-word visibility, which may have influenced whether or not a frequency by predictability interaction was obtained. Thus, overall, it is not clear whether the afore-mentioned studies would have obtained different outcomes if the materials were better controlled.

A recent eye-tracking study by Hand, Miellet, O'Donnell and Sereno (2006) which employed the same design as that used by Rayner et al. (2001, experiment 2; Rayner, et al., 2004; Ashby, et al., 2005), but used different and improved materials, provided evidence that frequency and predictability interact when launch position into the target is controlled. However, both the presence and the nature of the interaction were dependent upon launch site position. Specifically, when the eyes were between 1-3 characters away from the target word, a predictability effect was apparent for low-frequency words only, but when the eyes were between 4-6 characters from the target word, a predictability effect was apparent for high-frequency words only. There was no interaction at more distant (7-9 character) launch sites. These results therefore suggest that whether or not a frequency by predictability interaction is obtained, is modulated by the amount of information initially available in parafoveal preview.

The present study aims to determine whether the additive effects of frequency and predictability shown in the afore-mentioned eye-tracking studies are due to deficiencies in the experimental materials or whether it is the case that frequency and predictability only interact when the eyes are launched fairly close to the target word. The experimental design employed by Rayner et al. (2001, experiment 2; Rayner et al., 2004; Ashby et al., 2005) was used in the present study although their experimental materials were improved. Specifically, since the original experimental sentences did not appear to be very plausible, the sentences were therefore made more plausible and, where possible, the predictability of the sentences modified by making the sentences as constraining as possible. Furthermore, the length of the target words were better controlled here (they were made similar lengths in each of the sentences and identical lengths in each of the sentence pairs) and critically, the length of the word before the target word in each of the sentences was also controlled (they were again made similar lengths in each of the sentences and identical lengths in each of the sentence pairs). Since the length of the pre-target word is controlled here, it is likely that launch position into the target word is controlled, thus providing optimal conditions for investigating whether frequency and predictability interact. The data for launch position into the target word can then be compared with that reported by Hand et al. If launch position into the target word is on average, 1-3 characters, then in-line with Hand et al., a predictability effect for low-frequency words only would be expected. Whereas, if launch position is on average, 4-6 characters from the target word, then a predictability for high-frequency words only would be expected. No interaction would be expected at launch sites of 7-9 characters.

A second aim of this study is to determine whether there is any evidence for early Hypothesis Testing and Guessing Game models of reading (e.g. Goodman, 1967; Haber, 1978; Hochberg, 1978; Levin & Kaplan, 1970; Smith, 1971). According to these models, during fixation of a word, readers form a prediction about what the up-coming word will be, based on a combination of the contextual information provided by the sentence and parafoveal preview information. When the up-coming word is eventually fixated, the prediction is subsequently confirmed or disconfirmed. This theory could plausibly account for the predictability effect, since presumably less predictions are generated when contextual constraint is high than when it is low, meaning that it will take less time for a match to be made between the generated lexical candidates and the correct target word when contextual constraint is high.

The Hypothesis Testing and Guessing Game models of reading clearly predict that the reader should be less likely to form a prediction about an up-coming word when less useful parafoveal preview information is available. Thus, if the predictability effect can be accounted for by such models, then a predictability effect would not be expected to be obtained when the amount of preview information available is less than that available under normal reading circumstances. Therefore it is possible to test these models by varying the type of preview, and thereby the amount of useful preview information, available to the reader.

It should be recalled from Chapter 2, that an early study by Balota, Pollatsek and Rayner (1985) investigated whether the type of preview information initially available in parafoveal vision influenced processing strategy on predictable and unpredictable words. These authors showed a predictability effect which did not differ according to whether the prior preview was identical or visually similar to the up-coming word, although the effect disappeared following a visually dissimilar preview. This outcome therefore provides some evidence for the idea that the predictability effect is due to a process of word-prediction. This is because, it suggests that the less useful the parafoveal preview information, then the more difficult it is to form a prediction regarding the nature of the up-coming word.

In order to provide a test of the Guessing Game and Hypothesis Testing models, in the present study, a parafoveal preview manipulation is also employed so that the preview of the target word is either identical to the target word or is misspelled. Since the aim was to produce previews which would not actively mislead readers, both word shape and initial and final letters were maintained, this resulted in a degree of misspelling which was not as severe as that achieved in Balota et al.'s visually dissimilar condition but was more severe than in their visually similar condition. Thus, the preview is sufficiently misspelled so that it is unlikely that the reader will obtain much useful preview information. Similarly to Balota et al., the contingent boundary procedure (e.g. Rayner, 1979b) was employed so that the misspelled preview changed to its correctly spelled counter-part as the eyes crossed an invisible boundary located in the space between the pre-target and target word.

If it is the case that the predictability effect is driven by a process of word-prediction in which a combination of contextual and parafoveal information is used to generate predictions, then a predictability effect should be apparent following the identical preview but should disappear when less preview information is available, i.e. in the misspelled condition. It is further predicted that any effect of frequency will be modulated by the type of preview initially available in parafoveal vision. This is because, word-frequency effects are generally assumed to be lexical access effects (although c.f. Balota, 1990), and since lexical access begins with parafoveal processing of a word, then it is possible that the frequency effect will be inhibited by the misspelled preview. A frequency effect (in an orthodox direction) would however, be expected following the identical preview. Furthermore, if it is the case that both word-predictability and word-frequency are modulated by target-preview information then it would be expected that any interaction between frequency and predictability would also be modulated by target-preview.

4.2. Method

4.2.1. Participants

Thirty-two undergraduate students from the University of Dundee participated in the experiment. All of the participants were native English speakers with normal or corrected-to-normal vision and were either paid £3 to take part or received course credit.

4.2.2. Materials and Design

Two lists of 16 experimental sentence frames (32 in total) which were modified versions of those used by Rayner et al. (2001, experiment 2, Rayner et al., 2004; Ashby et al., 2005), were initially generated. Each sentence served as the context for two possible target words (these were 16 pairs of high-frequency and low-frequency words). In the sentence frames from List 1, the two possible target words were either a high-frequency word which was also predictable given the preceding sentence context or a low-frequency word which was unpredictable given the preceding sentence context. For example, in the sentence frame "Both of the boys had black eyes and sore knuckles after having a huge _______ earlier in the week", the high-frequency predictable word 'fight' as well as the low-frequency unpredictable word 'brawl' can fit into the sentence.

The experimental items were designed in a manner which meant that each pair of target words could also fit into a second (paired) sentence (the paired sentences were the sentences from List 2). In the sentences from List 2, the target high-frequency word was the unpredictable word and the target low-frequency word was the predictable word. For example, in the sentence frame “The landlord had to close the pub as there had been a bar room ______ which had caused much damage”, ‘brawl’ was the low-frequency predictable word and ‘fight’ was the high-frequency unpredictable word.

Since two possible words could fit into each of the sentences, this resulted in four item lists which corresponded to four base conditions in which the target word was either High-Frequency Predictable, High-Frequency Unpredictable, Low-Frequency Predictable or Low-Frequency Unpredictable. An additional ‘Preview’ factor was employed so that in the base conditions, the target-preview was identical to the target word, but in a further four conditions (which replicated the base conditions), the target-preview was misspelled. This produced 8 conditions in total (an example item illustrating each of the conditions is given in Figure 4.1 below).

ID/M H-F P “Both of the boys had black eyes and sore knuckles after having a huge *fight/frpbt* <u>fight</u> earlier in the week”.

ID/M L-F P “The landlord had to close the pub as there had been a bar room *brawl/biezl* <u>brawl</u> which had caused much damage”.

ID/M L-F UP “Both of the boys had black eyes and sore knuckles after having a huge *brawl/biezl* <u>brawl</u> earlier in the week”.

ID/M H-F UP “The landlord had to close the pub as there had been a bar room *fight/frpbt* <u>fight</u> which had caused much damage”.

Figure 4.1. An example item showing each of the eight conditions employed. The target words (underlined) could be either High- or Low-Frequency Predictable or Unpredictable. The parafoveal previews (italicized) of the target words could be either Identical or Misspelled.

The misspelled words were constructed by replacing the second, third and fourth letters of each of the correctly spelled target words with letters of similar width and height. Thus, as well as the 16 pairs of high- and low-frequency target words (32 in total), a set of 32 misspelled words were also employed. It should be recalled that 32 sentence frames were initially constructed but since either a high- or low-frequency word could fit into each sentence and since the target-preview could be either identical to the target word or misspelled, this resulted in 128 sentences in total. The target words, parafoveal previews and the two lists of sentence frames initially constructed are set out in Appendix A.

Each pair of target words that could fit into a sentence were matched for length and all target words were made roughly the same length. Mean word length was 5.6 characters (range 5-9) for the high-frequency target words and 5.5 characters (range 5 –9) for the low-frequency target words. The mean word frequency was 145 counts per million for the high-frequency target words and 9 counts per million for the low-frequency target words (estimated using the Kuçera & Francis, 1967 norms). The word prior to the target word in each of the 32 experimental sentences was also controlled. All of these words were of high frequency (mean = 230 counts per million) (Kuçera & Francis, 1967) and were of short-medium length (mean = 4.9 characters, range = 4-6 characters). The word prior to the target word was also matched for length in each of the sentence pairs. Sentences did not exceed 100 characters including spaces and sentence pairs were matched for overall length.

In order to determine the predictability of the target words, 30 undergraduate students who did not take part in the eye-tracking experiment completed a cloze task (see Appendix B for task instructions). In the cloze task, participants were presented with 34 sentence fragments. The first two were for practice purposes and the remaining 32 were fragments of the experimental sentences. Specifically, the fragments consisted of all the words leading up to the target word, and participants were asked to continue each sentence with the first word that came into their mind. This task took approximately 10 minutes to complete. The mean probabilities of completing each sentence with the target word are shown in Table 4.1 below. A 2 x 2 between-items ANOVA revealed that the mean predictability ratings were significantly higher for the predictable target words than for the unpredictable target words ($F(1,60) = 1937.05$, $p < 0.001$), while the mean predictability ratings did not significantly differ according to the frequency of the target word ($F(1,60) = 1.59$, $p = 0.21$).

Table 4.1. The mean probability of completing the sentence fragment with either the High-Frequency Predictable, High-Frequency Unpredictable, Low-Frequency Predictable or Low-Frequency Unpredictable target word.

Target Word	Mean probability of generating target	Range
High-Frequency Predictable	.90	.63 -1.0
Low-Frequency Predictable	.88	.63 - 1.0
High-Frequency Unpredictable	.03	.0 - .20
Low-Frequency Unpredictable	.00	.0 - .07

A further separate group of 13 undergraduate students established the plausibility of the experimental sentences. This task (see Appendix C for a copy of the task instructions given to participants) required participants to rate the plausibility of all 64 experimental sentences as well as 56 filler sentences (which comprised 28 plausible sentences and 28 implausible sentences) on a scale of 1-7. Specifically, the participants were asked to rate the likelihood of the event being described in the sentence actually being true. The task took approximately 30 minutes to complete and participants received course-credit in return. The mean plausibility ratings for each of the four experimental conditions are shown in Table 4.2 below. A 2 x 2 between-items ANOVA confirmed that measured sentence Plausibility did not differ according to either the predictability (F (1,60) = 0.19, p = 0.66), or the frequency (F (1,60) = 0.26, p = 0.62), of the target word.

Table 4.2. The mean plausibility ratings for the High-Predictable, Moderately-Predictable, Low-Predictable and Unpredictable sentence frames.

Target Word	Mean plausibility of sentence frame (out of 7)	Range
High-Frequency Predictable	6.1	3.7 – 6.8
Low-Frequency Predictable	6.0	3.9 – 6.9
High-Frequency Unpredictable	6.0	3.8 – 6.8
Low-Frequency Unpredictable	5.9	3.4 – 6.6

As well as the experimental sentences, 32 filler sentences and 18 comprehension questions were employed (every participant read all the filler sentences and answered all the comprehension questions). The comprehension questions were paired with some of the filler sentences and some of the experimental sentences. A further set of 8 sentences and 2 comprehension questions were used as practice items. Practice sentences and filler sentences contained correctly spelled target-previews.

The thirty-two participants were randomly assigned to one of 4 groups. Four item lists of 32 experimental sentences were constructed and each group of 8 participants was randomly allocated to one list. Each list included 4 items from each of the 8 conditions. The conditions were rotated in a counterbalanced manner that ensured that each item was unique to a particular list. Items 1-4, for example, contained High-Frequency Predictable Targets/Identical Previews in List A, High-Frequency Predictable Targets/Misspelled Previews in List B, High-Frequency Unpredictable

Targets/Identical Previews in List C and High-Frequency Unpredictable Targets/Misspelled Previews in List D. The particular allocation of items to lists was treated as a dummy factor in the analyses, as was the allocation of participants to experimental lists.

4.2.3. Apparatus

Participants' head-movements were constrained by the use of a dental wax bite bar and chin rest and their eye-movements were recorded using a Dr. Bouis pupil-centre computation Oculomotor interfaced to a 12-bit A-D device sampling X and Y position every 2ms. Viewing was binocular but only the movements of the right eye were monitored. The calibration range was 100 characters. The sentences were displayed in monopitch white text on a black screen at a viewing distance of 500mm. At this distance, one character subtended approximately 0.3 degrees of visual angle. Participants answered comprehension questions by pressing either a right or left button (for 'yes' or 'no' respectively) on an attached button-box.

The contingent change from 'misspelling' to 'no-misspelling' was achieved by writing directly to the video memory of the graphics control card and was not dependent on the refresh cycle of the display (see Kennedy, Pynte & Ducrot, 2002 for details). The contingent procedure ensured that the misspelling (if present) was displayed only while the eyes were to the left of an invisible boundary located after the last letter of the pre-target word. To ensure strict comparability between display conditions, the contingent procedure was also employed in the identical preview conditions (in which the target letters were replaced by themselves).

4.2.4. Procedure

On arrival, participants were provided with oral instructions. They were given background information regarding the nature of the experiment and informed of what was required. They were then asked to read a set of printed instructions before signing a consent form and receiving either payment or course-credit. The printed instructions (see Appendix D) informed participants that they should read the sentences normally and answer the comprehension questions which followed some of the sentences.

Following this, participants were set up optically. Participants were then given eight practice sentences and two comprehension questions, this practice phase included demonstration of the calibration technique. Calibration required the fixation of five points distributed evenly across the horizontal axis of the screen at the point where the experimental sentences were to be displayed. The initial calibration procedure lasted approximately five minutes and the calibration accuracy was checked after every four sentences during the experiment. If the calibration fell within tolerable limits, the experiment continued, if not, the calibration process was repeated.

Each trial began with the display of a fixation marker in the form of a small cross (+). When the computer detected stable fixation of the marker for at least 150ms, the marker was replaced by the display of the experimental sentence, each word separated by a single space. The fixation marker was located to the left so that the initial fixation fell three characters to the left of the first word in the sentence. After reading each sentence, participants had to press a button to continue and were then presented with either a comprehension question or a sequence of dashes. When presented with comprehension questions, participants had to respond “yes” or “no” using a button box. The entire experiment lasted approximately 30 minutes and participants were given two brief breaks.

4.3. Results and Discussion

The experimental sentences were divided into six zones, shown by the back-slashes as follows:

Both of the boys had black eyes and sore knuckles| after having a| huge| fight| earlier in| the week.

zone 1 *zone 2* *z3* *z4* *zone 5* *zone 6*

Data from zone 1, which comprised the first few words of the sentence, were not analysed. In order to determine whether the Frequency, Predictability or target-Preview exerted any early effects, analyses were carried out on zone 2 (the three words prior to the pre-target word) and on zone 3 (the pre-target word). The main zone of interest was zone 4 which contained the target word and analysis of this enabled investigation into any influence of target-Preview on the Predictability effect as well as the combined effects of Frequency and Predictability. Analysis of zone 5 (e.g. 'earlier in' in the example given) which comprised the two words following the target, was also undertaken in order to determine if there were any spill-over effects of either Frequency or Predictability. Data for zone 6, which comprised the remaining words of the sentence, were not analysed.

Only the measure of final fixation duration was analysed for zone 2. This is because, the content of this region was not controlled across items (the content was the same in only one of the two pairs of sentences and the content across pairs was not controlled for length or frequency), thus it did not make sense to analyse the data from most of the measures taken in this region. It was worthwhile examining the final fixation duration data however, because, it is likely that final fixations were towards the end of the region no matter what experimental sentence was being read and the eyes may therefore be picking up information from the zone 3 pre-target word (e.g. ‘huge’) which was controlled. The measures of first fixation, gaze and go-past duration, as well as re-reading time, total reading time and skipping rate were taken and analysed for zones 3, 4 and 5. Additionally, the measure of launch position from zone 3 into zone 4 was analysed. Only main effects and interactions which did not simultaneously involve both the Frequency and Predictability of the target word are reported for zones 2, 3 and 5: Frequency by Predictability interactions in these zones are not interpretable since they could be due to the differing context words surrounding the critical words (i.e. the surrounding context is the same for the High-Frequency Unpredictable and Low-Frequency Predictable conditions, but differs from that for the Low-Frequency Unpredictable and High-Frequency Predictable conditions).

Repeated measures analyses of variances (ANOVAs) were undertaken across the eight conditions, with participants (F_1) and items (F_2) as random variables.

Participants clearly read the sentences carefully as overall accuracy on the comprehension questions was 88%.

4.3.1. Analysis of zone 2-the region prior to the pre-target word

Table 4.3. Mean First-Fixation duration, Go-Past duration, Gaze duration, Re-reading time, Total Reading time and First Fixation duration (in ms) derived from zone 2.

	Identical Preview				Misspelled Preview				Correct Preview Advantage			
Measure	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**
First Fix	236	260	244	233	241	247	252	231	5	-13	8	-2
Gaze	504	517	505	516	515	519	502	521	11	2	-3	5
Go-past	554	590	577	580	631	586	587	580	77	-4	10	0
Re-reading	50	73	72	63	115	67	85	59	65	-6	13	-4
TRT	573	641	641	621	648	632	644	652	75	-9	3	31
Final Fix	239	251	233	230	225	229	237	235	-14	-22	4	5

Note: HF = High-Frequency, LF = Low-Frequency, P = Predictable, U = Unpredictable. TRT = Total Reading time.

There was a trend towards an interaction between the Predictability and Preview of the up-coming target word in final fixation durations, F_1 (1, 28) = 3.11, p = 0.09; F_2 (1, 24) = 3.74, p = 0.06. Figure 4.2 below shows that final fixations were (non-significantly) shorter when the up-coming target word was Predictable and the Preview was Misspelled than when it was Predictable and the Preview was Identical, F_1 (1, 28) = 2.79, p = 0.10; F_2 (1, 12) = 3.27, p = 0.09. This suggests that the predictability of the up-coming target word (which was at this point, at least two words down-stream), may have exerted a very early, albeit non-significant, effect on when the eyes would move and that the eyes were “attracted” to the target when it was a non-word.

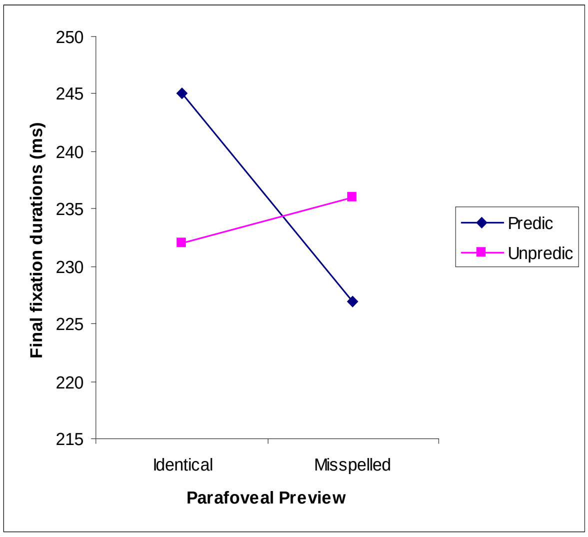


Figure 4.2. Final fixation durations in zone 2.

There were no other significant effects in final fixation durations, all F's < 1.

4.3.2. Analysis of zone 3-the pre-target word

Table 4.4. A range of Reading Time measures (in ms) derived from zone 3, together with probability of Skipping zone 3 (in characters).

	Identical Preview				Misspelled Preview				Correct Preview Advantage			
Measure	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**
Skip rate	0.11	0.22	0.17	0.21	0.16	0.15	0.16	0.11	N/A	N/A	N/A	N/A
First Fix	241	254	248	252	262	255	263	245	21	1	15	-7
Gaze	244	219	223	218	251	243	250	240	7	24	27	22
Go-past	265	246	252	245	267	291	283	269	2	45	31	24
Re-reading	21	28	29	27	16	48	32	29	-5	20	3	2
TRT	273	261	291	294	317	327	309	322	44	66	18	28

Note: HF = High-Frequency, LF = Low-Frequency, P = Predictable, U = Unpredictable. TRT = Total Reading time.

Figure 4.3 shows that there was a Frequency by Preview interaction in the pre-target-word skipping rate data, F_1 (1,28) = 9.08, p < 0.01; F_2 (1,24) = 7.18, p < 0.05. Specifically, when the Preview of the target was Identical, the pre-target word was more likely to be skipped when the target was of Low-Frequency than when it was of

High-Frequency, F_1 (1,28) = 4.29, $p < 0.05$; F_2 (1,24) = 7.74, $p < 0.05$. Additionally, when the target word was of Low-Frequency, the pre-target word was also significantly more likely to be skipped when the Preview of the target was Identical than when it was Misspelled, F_1 (1,28) = 5.44, $p < 0.05$; F_2 (1,12) = 7.81, $p < 0.05$.

The outcome of the significant Frequency by Preview interaction on skipping probability on the pre-target word points to one single significant effect: The pre-target word was more likely to be skipped when the target was of Low-Frequency and its Preview was Identical. On first reflection, this finding may seem odd since word-skipping is usually associated with high-frequency words. However, it should be borne in mind that since the decision to skip the pre-target word must have been made while the eyes were still in the previous zone, the skipping effect was in fact determined by properties of the target word which was at this point two words "downstream". There is evidence in the literature of pre-target word-skipping effects (e.g. Pynte, Kennedy & Ducrot, 2004; Kennedy & Pynte, 2005; Pynte & Kennedy, 2006), and it has been suggested that they are driven by sub-lexical properties of an up-coming target word. Pynte et al. (2004) have shown for example, that when an up-coming target word is an illegal non-word, the probability of skipping the pre-target word decreases. The present outcome is therefore compatible with their data.

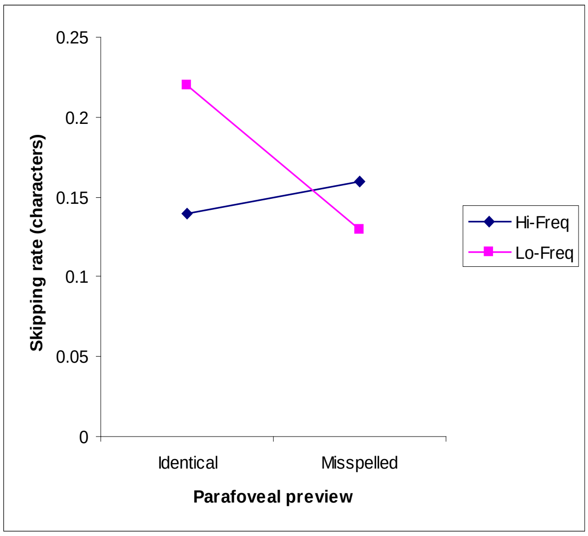


Figure 4.3. Skipping rate in zone 3.

There were no main effects of Frequency, Predictability or Preview and no other significant interactions in skipping rate data, all F's < 1 except Preview, F_1 (1,28) = 1.93, p = 0.17; F_2 (1,24) = 2.07, p = 0.16. There were also no main effects or interactions in first fixation durations, all F's < 1 except Frequency by Preview, F_1 (1,28) = 3.77, p = 0.06; F_2 (1,24) = 2.20, p = 0.15.

Table 4.4 shows that the nature of the target-Preview did affect gaze durations on the pre-target word. Gaze durations were 20ms slower when the Misspelled Preview was in parafoveal vision, F_1 (1,28) = 5.82, $p < 0.05$; F_2 (1,24) = 6.04, $p < 0.05$. This effect of parafoveal Preview was near-significant, and in the same direction, in the measure of go-past duration, F_1 (1,28) = 3.21, p = 0.08; F_2 (1,24) = 4.97, $p < 0.05$, and was significant in total reading times, F_1 (1,28) = 6.81, $p < 0.05$; F_2 (1,24) = 9.54, $p <0.01$. The effects in both gaze and go-past were not driven by an increase in the number of regressions made in zone 3 since there was no significant effect of Preview on re-reading time on the pre-target word, F_1 (1,28) = 0.24, p = 0.63; F_2 (1,24) = 0.30, p = 0.60. They can however, be considered as low-level parafoveal-on-foveal effects since they suggest that some parallel processing of the pre-target word and target-word preview took place. Such effects have previously been reported by Pynte, Kennedy and Ducrot (2002) although their effect was in the opposite direction (gaze duration on a currently fixated word decreased when a misspelled word was present in parafoveal vision).

No other effects were significant in either gaze, all F's < 1, or go-past, all F's < 1. Additionally, no other effects were significant in either re-reading times, all F's < 1, or total reading times, all F's < 1 except Predictability by Preview, F_1 (1,28) = 1.36, p = 0.25; F_2 (1,24) = 2.22, p = 0.15.

4.3.3. Analysis of zone 4-the target word (e.g. 'fight').

Table 4.5. A range of Reading Time measures (in ms) derived from zone 4, together with probability of Skipping zone 4 and average Launch Position of the saccade from zone 3 (in characters).

Measure	Identical Preview				Misspelled Preview				Correct Preview Advantage			
	HF P	LF P	HF U	LF U	HF P	LF P	HF U	LF U	HF P	LF P	HF U	LF U
Launch	-4.51	-4.9	-4.87	-4.95	-4.45	-4.5	-5.03	-4.61	N/A	N/A	N/A	N/A
Skip rate	0.2	0.15	0.15	0.14	0.13	0.1	0.06	0.12	N/A	N/A	N/A	N/A
First Fix	229	248	251	249	249	283	285	260	20	35	34	11
Gaze	189	223	234	239	258	275	326	278	69	52	92	39
Go-past	221	259	278	264	305	344	366	367	84	85	88	103
Re-reading	32	36	44	24	47	69	39	89	15	33	-5	65
TRT	221	264	297	326	327	322	379	394	106	58	82	68

Note: HF = High-Frequency, LF = Low-Frequency, P = Predictable, U = Unpredictable. TRT = Total Reading time.

Table 4.5 shows that there was no significant variation in launch position from zone 3 into zone 4, all F's < 1 except Predictability, F_1 (1, 28) = 1.38, p = 0.25; F_2 (1,24) = 2.38, p = 0.13.

There was a significant effect of target-Preview on the rate that the target word was skipped, F_1 (1,28) = 6.60, $p < 0.05$; F_2 (1,24) = 8.74, $p < 0.01$. Table 4.5 shows that the target word was more likely to be skipped when its preview had been Identical as opposed to Misspelled. Thus, when the misspelling was present in parafoveal vision, readers were more likely to subsequently fixate the target word. There was no effect of target Frequency, F's < 1 or Predictability, F_1 (1,28) = 3.88, $p = 0.06$; F_2 (1,24) = 1.39, $p = 0.25$, on the rate that the target word was skipped. These latter outcomes were surprising given that a well-documented finding is that high-frequency and high-predictable words are often skipped. There were also no significant interactions in the skipping rate data, all F's < 1 except Frequency by Predictability, F_1 (1,28) = 2.60, $p = 0.11$; F_2 (1,24) = 0.62, $p = 0.56$, and Frequency by Preview, F_1 (1,28) = 1.61, $p = 0.21$; F_2 (1,24) = 2.22, $p = 0.15$.

Table 4.5 shows that a significant effect of Preview was obtained in first fixation durations on the target word. Following the Identical preview, first fixation durations were faster by 25ms, F_1 (1,28) = 15.13, $p < 0.001$; F_2 (1,24) = 28.08, $p < 0.001$. This effect was also significant in gaze, F_1 (1,28) = 26.86, $p < 0.001$; F_2 (1,24) = 59.64, $p < 0.001$, go-past, F_1 (1,28) = 18.58, $p < 0.001$; F_2 (1,24) = 41.21, $p<0.001$, and total reading times, F_1 (1,28) = 22.73, $p < 0.001$; F_2 (1,24) = 45.72, $p < 0.001$. The effect just failed to reach significance in re-reading times, F_1 (1,28) = 3.45, $p = 0.07$; F_2 (1,24) = 4.36, $p < 0.05$, although the direction of the (non-significant) effect was consistent with the other Preview effects: More time was spent re-reading the target word when its Preview had been Misspelled. These outcomes indicate that less preview benefit was obtained in the Misspelled Preview condition and is consistent with Balota et al. (1985) and also Pynte et al. (2004, experiment 1) who similarly found that inspection times on a defined target word were longer when the target had been misspelled while in parafoveal vision.

The main effect of Predictability was not significant in first fixation durations, F_1 (1,28) = 2.80, p = 0.10; F_2 (1,24) = 1.88, p = 0.18. However, an effect (in the orthodox direction) was apparent in both gaze durations, F_1 (1,28) = 11.87, $p < 0.01$; F_2 (1,24) = 12.43, $p < 0.01$, and total reading times, F_1 (1,28) = 31.76, $p < 0.001$; F_2 (1,24) = 12.10, $p < 0.01$. These effects were not driven by time spent regressing, since there was no effect in either go-past durations, F_1 (1,28) = 5.69, $p < 0.05$; F_2 (1,24) = 2.63, p = 0.11, or re-reading times, F's < 1. It is also clear that the effects obtained in gaze and total reading times were not modulated by the nature of the target-Preview as the Predictability by Preview interaction was not significant in either gaze, F_1 (1,28) = 0.05, p = 0.82; F_2 (1,24) = 0.06, p = 0.81, or total reading times, F_1 (1,28) = 0.08, p = 0.78; F_2 (1,24) = 0.27, p = 0.61. This interaction was also non-significant in first fixations, F_1 (1,28) = 0.17, p = 0.69; F_2 (1,24) = 0.92, p = 0.65, go-past durations, F's < 1, and re-reading times, F's < 1. These outcomes therefore do not provide any evidence to suggest that the predictability effect is due to a process of word-prediction in which a combination of contextual and parafoveal information is used to make predictions.

Table 4.5 shows that the main effect of Frequency was not significant in either first fixation durations, F_1 (1,28) = 1.94, p = 0.17; $F_2 < 1$, gaze, F's < 1, go-past, F_1 (1,28) = 1.57, p = 0.22; $F_2 < 1$, re-reading times, F_1 (1,28) = 2.34, p = 0.13; $F_2 < 1$, or total reading times, F_1 (1,28) = 3.59, p = 0.07; $F_2 < 1$. The lack of frequency effects is somewhat peculiar. This is because the finding that high-frequency words are processed faster than low-frequency words is fairly robust. Thus, it is worthwhile investigating whether Frequency interacted with either Predictability or Preview.

In first fixation durations, there was a highly significant interaction between Frequency and Predictability, F_1 $(1,28) = 28.97$, $p < 0.001$; F_2 $(1,24) = 28.08$, $p < 0.001$. Figure 4.4 shows a significant effect of Frequency (in an orthodox direction) for Predictable words, F_1 $(1,28) = 25.67$, $p < 0.001$; F_2 $(1,24) = 4.65$, $p < 0.05$, and a significant effect of Predictability (in an orthodox direction) for High-Frequency words, F_1 $(1,28) = 24.39$, $p < 0.001$; F_2 $(1,24) = 7.51$, $p < 0.05$. Furthermore, and interestingly, there was an effect of Frequency (in an unorthodox direction) for Unpredictable words, F_1 $(1,28) = 3.98$, $p = 0.05$; F_2 $(1,24) = 4.10$, $p = 0.05$. Table 4.5 further shows that average launch position into the target word was 4-6 characters, meaning that the Frequency by Predictability interaction can be directly compared to that obtained by Hand et al. at similar launch sites. It will be recalled that at launch sites of 4-6 characters from the target word, Hand et al. obtained a predictability effect for high-frequency words only. Their outcome is clearly similar to that obtained here.

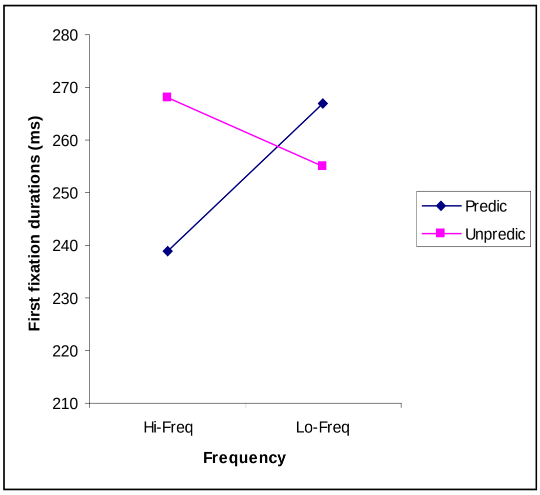


Figure 4.4. The form of the Frequency by Predictability interaction in first fixation durations in zone 4.

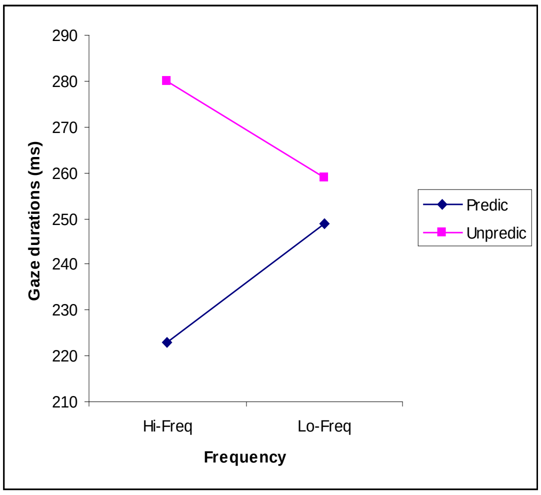


Figure 4.5. The form of the Frequency by Predictability interaction in gaze durations in zone 4.

The fact that Hand et al. found that Frequency and Predictability interacted at closer launch sites but not at distant launch sites, led them to conclude that whether the variables interact or not, is modulated by parafoveal preview information (presumably less preview information is available at distant launch sites). Although launch position was not manipulated in the present experiment, it was possible to investigate whether the present interaction was modulated by the type of preview information available by examining the Frequency by Predictability by Preview interaction. The 3-way interaction was not significant in first fixation durations, F_1 (1,28) = 2.65, p = 0.11; F_2 (1,24) = 4.07, p = 0.05, implying that the Frequency by Predictability interaction was not modulated by initial preview information. In order to clarify this, it was necessary to next examine whether Frequency by Predictability and Frequency by Predictability by Preview interactions were apparent in any of the other measures taken on the target word.

The Frequency by Predictability interaction was also significant in gaze, F_1 (1,28) = 9.66, p < 0.01; F_2 (1,24) = 5.61, p < 0.05, see Figure 4.5. Further analysis revealed a significant effect of Predictability for High-Frequency words, F_1 (1,28) = 19.92, $p < 0.001$; F_2 (1,12) = 18.43, $p < 0.01$. Thus, similarly to first fixation durations, there was facilitation for High-Frequency Predictable words and inhibition on High-Frequency Unpredictable words. The Frequency by Predictability by Preview interaction was far from significant in gaze, F_1 (1,28) = 1.23, $p = 0.28$; F_2 (1,24) = 1.17, $p = 0.81$, further suggesting that the interaction was not modulated by preview information.

The Frequency by Predictability interaction was not significant in go-past, F_1 (1,28) = 1.85, $p = 0.18$; $F_2 < 1$, re-reading times, F's < 1, or total reading times, F's < 1. The Frequency by Predictability by Preview interaction was also non-significant in go-past, F's < 1, re-reading times, F's < 1, and total reading times, F's < 1.

Thus far, the data suggest that neither the Predictability effect nor the combined effects of Frequency and Predictability were modulated by the information initially available in parafoveal preview, however it is informative to examine whether the Frequency effect is modulated by this. Given that the Frequency effect is generally thought to reflect lexical access (although c.f. Balota, 1990), target-preview-type may exert an influence on the effect.

There was no Frequency by Preview interaction in first fixation durations, F's < 1, however, there was a significant interaction in gaze, F_1 (1,28) = 6.80, $p < 0.05$; F_2 (1,24) = 5.91, $p < 0.05$. Figure 4.6 shows that for both High-Frequency words, F_1 (1,28) = 27.99, $p < 0.001$; F_2 (1,12) = 81.27, $p < 0.001$, and Low-Frequency words, F_1 (1,28) = 13.31, $p < 0.01$; F_2 (1,12) = 10.25, $p < 0.01$, gaze durations were significantly shorter following the Identical Preview than following the Misspelled Preview, implying that a Preview benefit was obtained in both the High- and Low-Frequency conditions. The fact that the Frequency effects following the Identical Preview, F_1

(1,28) = 4.42, $p < 0.05$; F_2 (1,12) = 1.91, $p = 0.18$, and Misspelled Preview, F_1 (1,28) = 1.69, $p = 0.20$; F_2 (1,12) = 1.04, $p < 0.32$, went in different directions, was clearly driving the interaction, however neither effect was statistically significant.

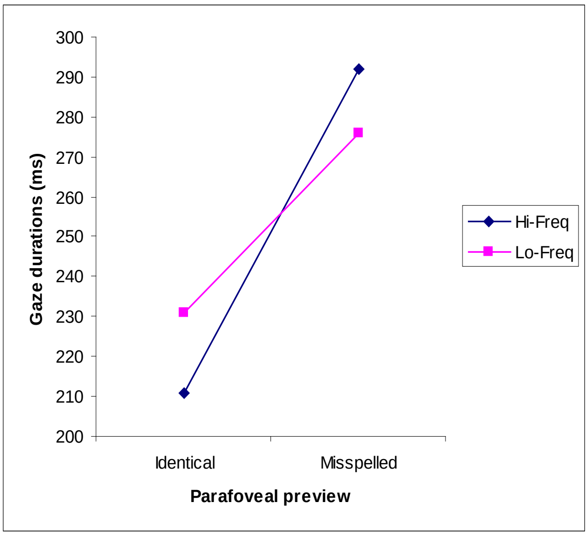


Figure 4.6. The form of the Frequency by Preview interaction in gaze durations in zone 4.

The Frequency by Preview interaction was not significant in go-past, F's < 1, re-reading times, F_1 (1,28) = 5.72, $p < 0.05$; F_2 (1,12) = 2.43, $p = 0.13$, or total reading times, F_1 (1,28) = 1.93, $p = 0.17$; F_2 (1,12) = 3.25, $p = 0.08$. This together with the fact that, statistically, the Frequency effect did not differ according to target-Preview in gaze, means that there was no concrete evidence to suggest that the Frequency effect was modulated by the nature of the target-Preview.

4.3.5. Analysis of zone 5-the region following the target word (e.g. 'earlier in')

Table 4.6. A range of Reading Time measures (in ms) derived from zone 5.

	Identical Preview				Misspelled Preview				Correct Preview Advantage			
Measure	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**
First Fix	244	231	247	246	243	238	244	246	-1	7	-3	0
Gaze	316	277	272	318	297	266	260	333	-19	-11	-12	15
Go-past	348	329	329	416	375	325	291	530	27	-4	-38	114
Re-reading	32	52	57	98	77	59	30	198	45	7	-27	100
TRT	408	364	373	412	392	351	356	472	-16	-13	-17	60

Note: HF = High-Frequency, LF = Low-Frequency, P = Predictable, U = Unpredictable. TRT = Total Reading time.

It should be recalled that given the nature of the materials, interactions simultaneously involving Frequency and Predictability were not analysed for zone 5.

Table 8.6 shows that there were no significant effects in either first fixation durations, all F's < 1 except Predictability, F_1 (1,28) = 1.72, p = 0.21; F_2 (1,24) = 1.31, p = 0.26, gaze durations, all F's < 1, go-past durations, all F's < 1 except Predictability, F_1 (1,28) = 5.35, p < 0.05; F_2 (1,24) = 1.18, p = 0.29, or total reading times, all F's < 1 except Predictability, F_1 (1,28) = 4.19, p < 0.05; F_2 (1,24) = 0.51, p = 0.51.

In fact the only significant effect in zone 5, was that of Frequency which influenced re-reading times, F_1 (1,28) = 11.92, p < 0.01; F_2 (1,24) = 4.87, p < 0.05, with longer reading times when the preceding target had been a Low-Frequency word compared to a High-Frequency word. This outcome suggests that more time was spent looking back towards the target word when it had been of Low-Frequency, and is consistent with the literature which shows greater spill-over for low-frequency words than for high-frequency words. Such post-lexical processing is sometimes assumed to reflect integration of target-word meaning with the previous sentence context. No other effects were significant in re-reading times, all F's < 1 except Predictability, F_1 (1,28) = 5.74, $p < 0.05$; F_2 (1,24) = 2.72, $p = 0.11$, and Preview, F_1 (1,28) = 2.15, $p = 0.15$; F_2 (1,24) = 2.56, $p = 0.12$.

4.4. General Discussion of Experiment 1

Before addressing the main issues investigated in this study, it is worthwhile discussing the effects relating to parafoveal preview which were obtained. Similar to the findings of Balota et al. (1985) and Pynte et al. (2004), the present study found that processing time on the target word significantly increased when the prior preview of the target had been misspelled while in parafoveal vision. There are at least two plausible explanations as to why this is the case. The first relates to the possibility that the misspelled previews caused the reader a reasonable amount of processing difficulty, suggesting that the preview difference was due to inhibition in the misspelled preview condition. Pynte et al. suggest that when the eyes eventually land on a restored target word, the absence of the misspelling causes a "surprise effect", resulting in an increase in inspection time on the target word. An alternative explanation is that there was less facilitation in the misspelled condition. It is difficult to tease apart these two theories, thus the issue of whether preview advantage, which has been reported in many previous studies, is due to facilitation in identical preview conditions or inhibition in misspelled preview conditions, at this point remains unresolved. However, Chapter 7 of this thesis provides an opportunity to resolve this issue.

The primary aim of Experiment 1 was to determine whether frequency and predictability exert interactive or additive effects on fixation durations, and evidence for the former was obtained. Using Additive Factors logic (e.g. Sternberg, 1969), this finding would imply that the two variables affect the same stage of word encoding. The fact that an interaction was obtained in the measure of first fixation duration, a measure assumed to capture lexical access, and since frequency effects are widely regarded as being related to related access, means that it is possible that predictability exerts its influence at the level of lexical access. Alternatively, it could be the case that both variables exert their effect at some post-access level, if it is assumed that post-lexical processing can occur fairly rapidly. It is not possible to discriminate between these two alternatives at this point and it would be premature to make any firm conclusions on the basis of the outcome of one experiment, thus this issue is also re-addressed later in this thesis.

The finding that frequency and predictability interact, contradicts a recent spate of eye-tracking studies (e.g. Rayner et al., 2004; Rayner et al., 2001; Ashby, et al., 2005; Altarriba, et al., 1996; Lavigne, et al., 2000; Kennedy et al., submitted) and also the current form of the *E-Z Reader* model, which suggest that frequency and predictability combine additively. It should be recalled that whilst the *E-Z Reader* model proposes that frequency and predictability affect both an initial and a later stage of word encoding, the variables are not predicted to interact in each of these stages. The results also disagree with early word-recognition studies which showed larger predictability effects for low-frequency words (e.g. Stanovich & West, 1979; 1983; West & Stanovich, 1982; Becker, 1979) since the present interactions were instead driven by a large predictability effect for high-frequency words. That is, there appeared to be facilitation for high-frequency predictable words and inhibition for high-frequency unpredictable words. The facilitation for the high-frequency predictable words probably arises from the fact that the predictable words employed were very predictable given the preceding sentence context, thus it is likely that high-frequency words which are also very predictable, are activated and verified fairly quickly during the reading process. It is less clear why the high-frequency unpredictable words took longer to process than the low-frequency predictable and low-frequency unpredictable words. The most parsimonious explanation is that the high-frequency unpredictable words were particularly unexpected given the preceding sentence context, thus causing the reader some processing difficulty.

The fact that a predictability effect was obtained for high-frequency words corroborates research by Hand et al. (2006) which also showed a significant predictability effect for high-frequency words at launch sites of 4-6 characters from the target word. From their research, Hand et al. conclude that frequency and predictability interactions are modulated by the amount of parafoveal preview information available since variations in launch position can determine this. However, it is unlikely that the interaction is dependent upon the amount of preview information available, given that the present interactions were not modulated by the nature of the target-preview. That is, a smaller preview advantage was obtained following the misspelled preview than the identical preview, indicating that less useful preview information was initially available in the misspelled condition, yet this did not influence the frequency and predictability interaction. This suggests that the additive effects of frequency and predictability reported in previous studies may be due to the fact that the experimental materials were not well-controlled, rather than due to variations in the amount of parafoveal preview information initially available.

This study also investigated whether the predictability effect can be accounted for by Hypothesis Testing and Guessing Game models of reading which suggest that readers use a combination of contextual and parafoveal preview information to make predictions about up-coming words. It should be recalled that this type of theory predicts that predictable words will be processed faster than unpredictable words since presumably less predictions are generated when contextual constraint is high than when it is low. That is, it should take less time for a match to be made between the generated lexical candidates and the correct target word when contextual constraint is high. It further predicts that a reader will be less likely to form a prediction about an up-coming word when the parafoveal preview of this word is misspelled, since less useful preview information will be available to the reader. While the present study obtained target-predictability effects, there was no evidence to suggest that these were modulated by whether the target-preview was identical to the target word or misspelled. This outcome therefore appears to provide evidence against the Hypothesis Testing and Guessing Game models. Having said this, it is possible that the degree of the misspelling achieved in the misspelled preview condition was not severe enough, meaning that the reader was able to obtain enough useful preview information in order to form a prediction about the up-coming word. It should be recalled that while Balota et al. (1985) showed that their predictability effects were not modulated by whether the prior preview was identical or visually similar to the target word, the effects did disappear following the visually dissimilar preview.

If it is in fact the case that readers obtained some useful preview information in the misspelled preview condition, then the present outcome may not necessarily be at odds with either the Hypothesis Testing and Guessing Game models of reading, or Hand et al.'s research which suggests that whether or not a frequency by predictability interaction is obtained, is dependent upon the amount of parafoveal preview information initially available. Thus, an obvious next step is to investigate the nature of frequency and predictability effects, and the combined effects of both, when the target-preview is either identical to the target word or severely misspelled. This experiment is reported in Chapter Five.

Chapter 5:

Are frequency and predictability effects modulated by parafoveal preview information?

5.1. Introduction

The aim of Experiment 2 is to address unresolved issues raised in Experiment 1. It should be recalled that Experiment 1 set out to investigate whether frequency and predictability exert additive or interactive effects on fixation durations, while a further aim was to determine whether the predictability effect is the result of a process of word-prediction in which readers use a combination of contextual and parafoveal preview information to make predictions.

The reason for investigating whether or not frequency and predictability interact in fixation durations was to help identify the locus and therefore the nature of the predictability effect. The outcome of Experiment 1 was that frequency and predictability interacted in various measures of inspection time, including that of first fixation duration, suggesting that both variables exert a very early influence during word encoding, possibly at the lexical access stage. However, since this outcome is at odds with a spate of eye-tracking studies which have shown additive effects of the two variables (e.g. Rayner, Ashby, Pollatsek & Reichle, 2004; Altarriba, Kroll, Sholl & Rayner, 1996; Lavigne, Vitu & d'Ydewalle, 2000; Rayner, Binder, Ashby & Pollatsek, 2001; Ashby, Rayner & Clifton, 2005; Kennedy, Pynte, Murray & Paul, submitted), this means that it would be premature at this point to conclude that frequency and predictability influence the same stage of word encoding.

The results of Experiment 1 were however, in-line with a study by Hand, Miellet, O'Donnell and Sereno (2006) which has also provided evidence to suggest that frequency and predictability interact. Similarly to Hand et al.'s research, Experiment 1 revealed a predictability effect for high-frequency target words when the eyes were launched 4-6 characters from the target word. It should be recalled that Hand et al. further showed that when the eyes were 1-3 characters from the target word, a predictability effect was obtained for low-frequency words only, whilst frequency and predictability did not interact at more distant launch sites (7-9 characters from the target word). These outcomes led Hand et al. to conclude that whether or not an interaction is obtained, is dependent upon the amount of target-preview information initially available to the reader. However, the frequency by predictability interactions apparent in Experiment 1 were not modulated by the type of preview initially available, and if it was the case that less useful parafoveal preview information was available in the misspelled preview condition than in the identical preview condition, this means that Experiment 1 provides evidence against Hand et al.'s proposal. However, if it was actually the case that readers were able to extract a relatively similar amount of visual information in both preview conditions, then Hand et al.'s proposal cannot at this point, be refuted.

Experiment 1 also investigated whether the predictability effect is due to a process of word-prediction in which readers use a combination of contextual and parafoveal preview information to form a prediction about an up-coming word, and then either confirm or disconfirm this prediction when the word is eventually fixated. This process is inherent in Hypothesis Testing and Guessing Game models of reading (e.g. Goodman, 1967; Haber, 1978; Hochberg, 1978; Levin & Kaplan, 1970; Smith, 1971), and it will be recalled that these models could potentially account for the predictability effect since presumably less predictions are generated when contextual constraint is high than when it is low, meaning that it should take less time for a match to be made between the generated lexical candidates and the correct target word when contextual constraint is high. Since these models predict that the reader should be less able to form a prediction when no useful parafoveal information is available, in the previous chapter it was hypothesised that if the predictability effect is one relating to word-prediction, then no word-predictability effect should be apparent when the preview of this word is not informative.

Experiment 1 showed that the predictability effect was not dependent upon whether the prior preview was misspelled or not, an outcome which should provide evidence against the idea that the predictability effect is due to a process of word-prediction. However, it should be recalled that Balota, Pollatsek and Rayner (1985) showed that while their predictability effect (which was apparent following an identical preview) disappeared following a visually dissimilar preview, it did not disappear following a visually similar preview. Their findings therefore suggest that readers obtained a relatively similar amount of useful preview information in both the identical and visually similar misspelled preview conditions, otherwise the predictability effect would have been eradicated in both the visually similar and visually dissimilar preview conditions. Although the degree of the misspelling achieved in Experiment 1 was more severe than that achieved in Balota et al.'s visually similar preview condition, it was not as severe as that achieved in Balota et al.'s visually dissimilar preview condition. This means that it is possible that readers acquired a similar amount of useful preview information in both of the preview conditions employed in Experiment 1. If this was the case, then this means that the previous experiment did not provide an adequate test of the word-prediction hypothesis.

Whether or not frequency by predictability interactions are dependent upon the amount of parafoveal preview information initially available, and whether or not the predictability effect can be accounted for by a process of word-prediction, can be further investigated by employing a more severely misspelled preview condition than that employed in the previous experiment. Thus, the present experiment replicated Experiment 1 but the misspelled previews were now more severely misspelled. The degree of the misspelling achieved is similar to that achieved by Balota et al. in their visually dissimilar preview condition. In their experiment, the visually dissimilar preview of the target word ‘money’, for example, was the non-word ‘toohz’. In the present experiment, all of the target-word letters were also altered to produce visually dissimilar misspelled previews, for example, the visually dissimilar preview of the target word ‘fight’ is the word ‘oetgc’. Similarly to Experiment 1, the contingent boundary procedure was employed so that the misspelling was only ever available while in parafoveal vision.

The misspelled previews employed here should ensure that no useful lexical information will be available to the reader. Thus, if it is the case that frequency and predictability only interact when there is sufficient preview information initially available to the reader, then a frequency by predictability by preview interaction would be expected in the present study. Specifically, since Hand et al.’s data suggest that frequency and predictability are less likely to interact when less of the up-coming word is visible, then there should be no frequency by predictability interaction in the visually dissimilar misspelled condition. However, a frequency by predictability interaction, similar in form to that obtained in Experiment 1, should be obtained in the identical preview condition.

If the predictability effect is the result of a process of word-prediction, then an effect of predictability should be apparent in the identical preview condition but not in the visually dissimilar preview condition since there will be no useful preview information in order to help make a prediction about the nature of the up-coming word in this latter condition.

5.2. Method

5.2.1. Participants

Thirty-two undergraduate students from the University of Dundee participated in the study. All of the participants were native English speakers with normal or corrected-to-normal vision and were either paid £3 to take part or received course credit.

5.2.2. Materials and Design

The 16 sentence frames and 16 pairs of correctly spelled high- and low-frequency target words employed in Experiment 1 were also used in Experiment 2. Thus, the predictability of the target words and the plausibility of the experimental sentences were unchanged (see Appendices B and C). However, in this study, the 16 pairs of misspelled preview words were more severely misspelled. This degree of misspelling was achieved by making the misspelled previews visually dissimilar to their correctly-spelled counter-parts. Specifically, the visually dissimilar previews (see Appendix A) were constructed by randomly selecting letters from the 32 correctly spelled target words, ensuring therefore that the misspelled previews were controlled for pixel density. The only restriction using this method was that a letter could not be used, and was therefore put back in the letter-pile, if it was similar in shape and/or width to the letter which was in the same letter-position in the correctly spelled counter-part. Thus, for example, the letter ‘o’ could not be replaced with ‘a’, but could be replaced with the letter ‘l’.

Similarly to Experiment 1, eight conditions were employed which included four ‘base’ conditions in which the target-preview was identical to the target word and four conditions in which the target-preview was visually dissimilar to the target word. An example item illustrating each of these conditions is given in Figure 5.1.

ID/VD H-F P “Both of the boys had black eyes and sore knuckles after having a huge *fight/oetgc* fight earlier in the week”.

ID/VD L-F P “The landlord had to close the pub as there had been a bar room *brawl/cosla* brawl which had caused much damage”.

ID/VD L-F UP “Both of the boys had black eyes and sore knuckles after having a huge *brawl/cosla* brawl earlier in the week”.

ID/VD H-F UP “The landlord had to close the pub as there had been a bar room *fight/oetgc* fight which had caused much damage”.

Figure 5.1. An example item showing each of the eight conditions employed. The target words (underlined) could be either High- or Low-Frequency Predictable or Unpredictable. The parafoveal previews (italicized) of the target words could be either Identical or Visually Dissimilar misspelled.

Also similar to Experiment 1, the eight conditions were manipulated within groups of participants and within items. The way in which participants were assigned to groups and items to lists was also the same.

The 32 filler sentences, 18 comprehension questions and 8 practice items employed in Experiment 1 were also employed in Experiment 2.

5.2.3. Apparatus

The apparatus was exactly the same as that employed in Experiment 1.

5.2.4. Procedure

The procedure was exactly the same as that employed for Experiment 1.

5.3. Results and Discussion

The experimental sentences were divided into six zones. The zones analysed were the same as those analysed in Experiment 1 and the measures taken and the way in which the analyses were carried out, were also the same. Only main effects and interactions which did not simultaneously involve both the Frequency and Predictability of the target word are reported for zones 2, 3 and 5 (see section *4.3*).

Overall accuracy on the comprehension questions was 88% indicating that participants read the sentences carefully.

5.3.1. Analysis of zone 2-the region prior to the pre-target word

Table 5.1. Mean First-Fixation duration, Go-Past duration, Gaze duration, Re-reading time, Total Reading time and First Fixation duration (in ms) derived from zone 2.

	Identical Preview				Visually Dissimilar Preview				Correct Preview Advantage			
Measure	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**
First Fix	249	253	255	249	248	247	249	249	-1	-6	-6	0
Gaze	485	478	457	502	496	454	467	502	11	-24	10	0
Go-past	526	552	554	621	581	568	601	608	55	16	47	-13
Re-reading	41	74	97	119	85	114	134	106	44	40	37	-13
TRT	571	591	654	674	639	666	625	662	68	75	-29	-12
Final Fix	244	226	253	235	245	233	232	253	1	7	-21	18

Note: HF = High-Frequency, LF = Low-Frequency, P = Predictable, U = Unpredictable. TRT = Total Reading time.

In Experiment 1 it was shown that there was a trend towards an interaction between the effects of Predictability and the Preview of the up-coming target word in the measure of final fixation duration in zone 2. In the present experiment, there was no such interaction, F_1 (1,28) = 0.28, p = 0.61; F_2 (1,24) = 0.28, p = 0.61. There was, however, a significant interaction between Frequency and the nature of the Preview of the zone 4 word, F_1 (1,28) = 7.56, $p < 0.01$; F_2 (1,24) = 4.01, p = 0.05. Figure 5.2 shows that for Identical Previews, fixation durations were shorter when the up-coming target word was of Low-Frequency than when it was of High-Frequency, F_1 (1,28) = 5.65, $p < 0.05$; F_2 (1,24) = 2.23, p = 0.15, although the effect failed to reach significance in the item analyses. There was no effect of Frequency when the zone 4 preview was Visually Dissimilar misspelled, F_1 (1,28) = 0.77, p = 0.61; F_2 (1,24) = 0.66, p = 0.57. During the final fixation of zone 2, the eyes were likely to have been towards the end of the zone 2 region, meaning that the target-preview would have been in the readers' attentional span. Thus, it is not implausible that target-frequency could have exerted an effect at this point. The fact that there was no such effect in the misspelled preview condition is not surprising given that the misspelled preview would not have provided the reader with any lexical information.

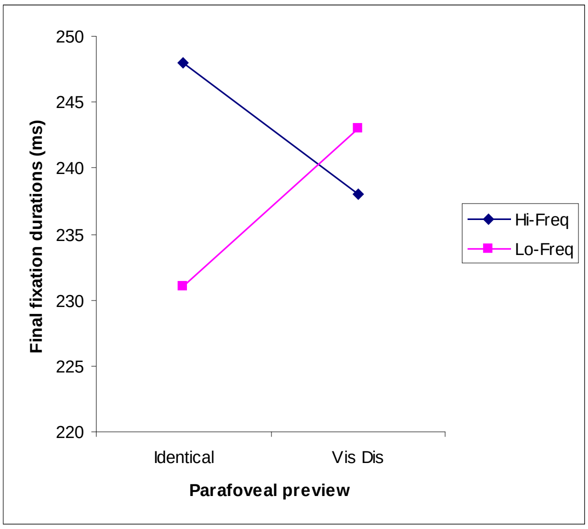


Figure 5.2. Final fixation durations in zone 2.

There were no other significant effects in the final fixation duration data, all F's < 1.

5.3.2. Analysis of zone 3-the pre-target word

Table 5.2. A range of Reading Time measures (in ms) derived from zone 3, together with probability of Skipping zone 3 (in characters).

	Identical Preview				Visually Dissimilar Preview				Correct Preview Advantage			
Measure	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**
Skip rate	0.27	0.19	0.23	0.23	0.16	0.16	0.21	0.17	N/A	N/A	N/A	N/A
First Fix	267	260	266	250	266	262	278	263	-1	2	12	13
Gaze	211	219	232	208	241	229	265	241	30	10	33	33
Go-past	247	260	308	227	298	297	310	276	51	37	2	49
Re-reading	35	41	76	20	57	69	45	35	22	28	-31	15
TRT	254	262	308	290	349	321	383	369	95	59	75	79

Note: HF = High-Frequency, LF = Low-Frequency, P = Predictable, U = Unpredictable. TRT = Total Reading time.

Table 5.2 shows that the nature of the zone 4 Preview significantly influenced how likely it was that the zone 3 word would be skipped, F_1 (1,28) = 5.17, $p < 0.05$; F_2 (1,24) = 5.16, $p < 0.05$, with a greater skipping rate when the target-Preview was not misspelled. Of course, the decision to skip the zone 3 word must have been made while the eyes were still processing the words in zone 2. Thus, the early skipping effect suggests that when the zone 4 preview was misspelled, readers were more likely to fixate the zone 3 word and thus read the sentence more carefully.

Target Preview-type did not influence first fixation durations in zone 3, F_1 (1,28) = 1.65, $p = 0.21$; $F_2 < 1$, but did influence gaze durations, F_1 (1,28) = 7.25, $p < 0.05$; F_2 (1,24) = 7.98, $p < 0.01$, go-past durations, F_1 (1,28) = 4.79, $p < 0.05$; F_2 (1,24) = 6.86, $p < 0.05$, and total reading times, F_1 (1,28) = 17.42, $p < 0.001$; F_2 (1,24) = 46.93, $p < 0.001$. Consistent with the outcome of Experiment 1, inspection times were longer when the Preview of the up-coming target word was misspelled. This suggests that readers were either surprised by the presence of the misspelling and/or were trying to make sense of it. Overall, this outcome suggests that a certain amount of parallel processing took place but is not necessarily at odds with a serial processing viewpoint. According to the *E-Z Reader* model, for example, during an early visual processing stage of word-encoding, low-spatial-frequency visual information from across the whole page is acquired and is processed in parallel.

No other effects were significant in either first fixation durations, all F's < 1 except Frequency, F_1 (1,28) = 2.00, $p = 0.17$; $F_2 < 1$, gaze durations, all F's < 1 except Predictability, F_1 (1,28) = 1.33, $p = 0.26$; F_2 (1,24) = 2.08, $p = 0.16$, go-past durations, all F's < 1, except Frequency, F_1 (1,28) = 2.10, $p = 0.15$; F_2 (1,24) = 0.85, $p = 0.63$, or re-reading times, all F's < 1. Thus, there was no evidence of any high-level parafoveal-on-foveal effects.

A main effect of Predictability was apparent in total reading times, F_1 (1,28) = 4.90, $p < 0.05$; F_2 (1,24) = 9.34, $p < 0.01$, with longer total reading times when the up-coming target word was Unpredictable. Since this measure includes fixations after the reader has gone past the word, and since there were no predictability effects in any of the first pass measures, suggests that this effect was not a parafoveal-on-foveal effect. There were no other significant effects in total reading times, all F's < 1.

5.3.3. Analysis of zone 4-the target word

Table 5.3. A range of Reading Time measures (in ms) derived from zone 4, together with probability of Skipping zone 4 and average Launch Position of the saccade from zone 3 (in characters).

	Identical Preview				Visually Dissimilar Preview				Correct Preview Advantage			
Measure	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**
Launch	-6.61	-5.92	-5.89	-5.44	-4.95	-5.30	-4.90	-5.05	N/A	N/A	N/A	N/A
Skip rate	0.2	0.13	0.2	0.13	0.1	0.11	0.12	0.06	N/A	N/A	N/A	N/A
First Fix	229	244	257	264	288	288	276	290	59	44	19	26
Gaze	188	227	229	253	299	325	314	309	111	98	85	56
Go-past	213	286	283	309	436	407	413	380	223	121	130	71
Re-reading	25	58	54	56	137	81	99	72	112	23	45	16
TRT	226	270	307	330	376	399	431	424	150	129	124	94

Note: HF = High-Frequency, LF = Low-Frequency, P = Predictable, UP = Unpredictable. TRT = Total Reading time.

Table 5.3 shows that launch position of the saccade exiting zone 3 was influenced by the nature of the target-Preview, F_1 (1,28) = 10.73, $p < 0.01$; F_2 (1,24) = 20.14, $p < 0.001$. Launch positions were closer to the target word when its preview was misspelled, implying that readers moved their eyes closer in an attempt to make sense of the misspelling. No other effects of launch position from zone 3 were significant, all F's < 1, except Predictability, F_1 (1,28) = 1.65, $p = 0.21$; F_2 (1,24) = 3.73, $p = 0.06$, and Frequency by Preview, F_1 (1,28) = 1.71, $p = 0.20$; F_2 (1,24) = 1.14, $p = 0.30$.

The rate at which the target word was skipped was also influenced by the nature of the target-Preview, F_1 (1,28) = 8.84, $p < 0.01$; F_2 (1,24) = 11.86, $p < 0.01$. Similarly to

Experiment 1, the target word was more likely to be skipped if its Preview was Identical than if it was misspelled, further implying that readers adopted a more careful and thorough reading strategy when the word was misspelled.

There was also a significant Frequency by Preview interaction in skipping rate in zone 4, F_1 (1,28) = 6.75, $p < 0.05$; F_2 (1,24) = 7.06, $p < 0.05$. Figure 5.3 shows that High-Frequency target words were less likely to be skipped when the target-Preview was misspelled than when it was identical, F_1 (1,28) = 19.95, $p < 0.001$; F_2 (1,12) = 13.26, $p < 0.01$, while there was no such Preview effect for Low-Frequency words, F_1 (1,28) = 0.18, $p = 0.68$; F_2 (1,12) = 0.52, $p = 0.51$. This outcome is consistent with a vast amount of literature which shows that high-frequency words are skipped more often than low-frequency words.

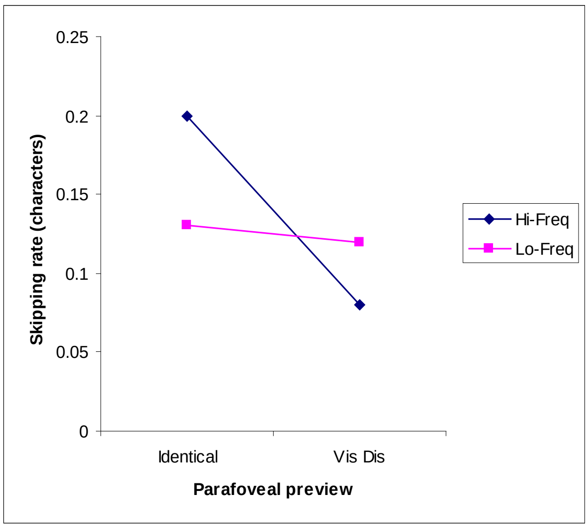


Figure 5.3. Skipping rate in zone 4.

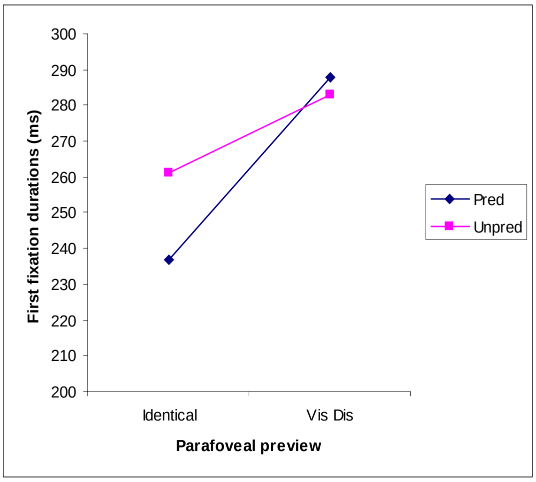
There were no other significant effects in the skipping rate data for zone 4, all F's < 1.

Table 5.3 further shows that first fixation durations were longer when the target-Preview had been Visually Dissimilar to the target than when it had been Identical, F_1

(1,28) = 40.84, $p < 0.001$; F_2 (1,24) = 20.29, $p < 0.001$. The magnitude of the advantage was greater in Experiment 2 (38ms) than in Experiment 1 (25ms), indicating that less useful preview information was obtained in the misspelled preview condition in the present experiment. This preview advantage was also shown in gaze, F_1 (1,28) = 54.45, $p < 0.001$; F_2 (1,24) = 134.44, $p < 0.001$, go-past, F_1 (1,28) = 43.08, $p < 0.001$; F_2 (1,24) = 60.37, $p < 0.001$, and total reading times, F_1 (1,28) = 109.77, $p < 0.001$; F_2 (1,24) = 100.39, $p < 0.001$. Additionally, more time was spent looking back towards zone 3 when the target-Preview had not matched the target word, F_1 (1,28) = 10.36, $p < 0.01$; F_2 (1,24) = 9.67, $p < 0.01$.

There was no main effect of Predictability in either first fixation durations, F_1 (1,28) = 2.18, $p = 0.15$; F_2 (1,24) = 1.74, $p = 0.20$, gaze durations, F_1 (1,28) = 2.35, $p = 0.13$; F_2 (1,24) = 6.87, $p < 0.05$, go-past durations, F’s < 1, or re-reading times, F’s < 1. However, total reading times were significantly shorter for Predictable words than for Unpredictable words, F_1 (1,28) = 16.88, $p < 0.001$; F_2 (1,24) = 9.35 $p < 0.01$.

A Predictability by Preview interaction was apparent in first fixation durations, F_1 (1,28) = 4.95, $p < 0.05$; F_2 (1,24) = 8.66, $p < 0.01$. Figure 5.4 shows that similarly to Experiment 1, first fixation durations were significantly shorter on Predictable words than on Unpredictable words following the Identical Preview, F_1 (1,28) = 13.22, $p < 0.01$; F_2 (1,24) = 11.87, $p < 0.01$. However, dissimilarly to Experiment 1, there was no Predictability effect following the Visually Dissimilar Preview, F’s < 1. Thus, the target-predictability effect was dependent upon the target-preview being available for processing, an outcome which is compatible with the idea that readers use a combination of contextual and parafoveal information to make predictions about up-coming words.



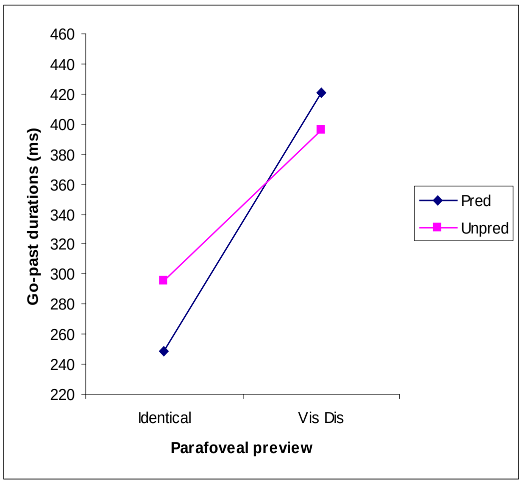


Figure 5.4. The form of the Predictability by Preview interaction in first fixation durations in zone 4.

Figure 5.5. The form of the Predictability by Preview interaction in go-past durations in zone 4.

The Predictability by Preview interaction shown in first fixation duration did not achieve significance in gaze, F_1 (1,28) = 3.20, p = 0.08; F_2 (1,24) = 3.17, p = 0.08, but, it was significant in go-past, F_1 (1,28) = 5.03, $p < 0.05$; F_2 (1,24) = 4.26, $p < 0.05$. Figure 5.5 shows an interaction that is very similar in form to that obtained in first fixation duration. Again, there was a Predictability effect following the Identical Preview, F_1 (1,28) = 5.80, $p < 0.05$; F_2 (1,24) = 5.82, $p < 0.05$, but no effect following the Visually Dissimilar Preview, F's < 1. The Predictability by Preview interaction was not critically dependent on regressions as there was no interaction in re-reading times, F_1 (1,28) = 2.34, p = 0.13; F_2 (1,24) = 1.59, p = 0.22, and was less clear in the overall reading times, F_1 (1,28) = 1.18, p = 0.29; $F_2 < 1$.

The fact that Predictability and Preview interacted clearly differs to the outcome of Experiment 1 in which no such interaction was obtained, and as hypothesised, must be due to the fact that the degree of the misspelling achieved here was more severe than that achieved in Experiment 1. That is, it appears that in contrast to Experiment

1, readers were not able to extract any useful preview information in the misspelled Preview condition, and consequently, no predictability effect was obtained.

Similarly to Experiment 1, the effect of Frequency was not significant in either first fixation durations, F_1 (1,28) = 3.68, p = 0.06; F_2 (1,24) = 1.28, p = 0.27, gaze durations, F_1 (1,28) = 3.62, p = 0.06; F_2 (1,24) = 2.60, p = 0.12, go-past durations, F's < 1, re-reading times, F's < 1, or total reading times, F_1 (1,28) = 1.50, p = 0.23; F_2 (1,24) = 1.72, p = 0.20.

In contrast to Experiment 1, the Frequency by Predictability interaction was not significant in either first fixation duration, F_1 (1,28) = 0.04, p = 0.84; F_2 (1,24) = 0.06, p = 0.81, or gaze duration, F_1 (1,28) = 1.70, p = 0.20; F_2 (1,24) = 2.02, p = 0.16. It was also non-significant in go-past, F's < 1, re-reading time, F's < 1, and total reading time, F's < 1. In addition, there was no evidence to suggest that the interaction was present following either the Identical Preview or Visually Dissimilar Preview only as the Frequency by Predictability by Preview interaction was not significant in any of the inspection time measures taken, all F's < 1.

It was somewhat surprising that no Predictability by Frequency by Preview interactions were apparent in Experiment 2. The results from Experiment 1 suggest that it should be possible to obtain a Frequency by Predictability interaction in the Identical Preview condition at least. Thus, Between-experiments ANOVAs were conducted in order to determine whether the Frequency by Predictability interaction which was apparent in first fixation and gaze durations in Experiment 1 was apparent across both experiments.

The first fixation duration data showed the interaction in Experiment 1 only: The joint effects of Frequency and Predictability significantly differed between experiments, F_1 (1,56) = 10.79, $p < 0.01$; F_2 (1,24) = 9.59, $p < 0.01$, and the interaction was not reliable in the item analysis when taken across both experiments, F_1 (1,56) = 8.76, $p < 0.01$; $F_2 < 1$.The results of the analyses for gaze were less clear however. While the interaction overall was not significant, F_1 (1,56) = 9.01, $p < 0.01$; F_2 (1,24) = 1.60, $p = 0.20$, there was, however, no evidence to suggest that the joint effects of Frequency and Predictability differed between experiments, F_1 (1,56) = 1.02 $p = 0.32$; F_2 (1,24) = 1.12, $p = 0.30$.

On balance, it appears that the Frequency by Predictability interaction was really only apparent in Experiment 1, thus the interaction in Experiment 1 does not in itself seem to be good evidence to suggest that frequency and predictability influence the same stage of word encoding. This issue is returned to in section *5.4*.

The Frequency by Preview interaction was not significant in either first fixation duration, F's < 1, or gaze duration, F_1 (1,28) = 1.56, $p = 0.22$; F_2 (1,24) = 2.67, $p = 0.11$. However, it was significant in the measure of go-past, F_1 (1,28) = 3.88, $p = 0.06$; F_2 (1,24) = 6.58, $p < 0.05$. Figure 5.6 shows that for Identical Previews, go-past durations were significantly shorter when the target was of High-Frequency than when it was of Low-Frequency, F_1 (1,28) = 5.20, $p < 0.05$; (F_2 (1,24) = 6.21, $p < 0.05$. There was no Frequency effect following the Visually Dissimilar Preview, F's < 1. The Frequency by Preview interaction was not significant in either re-reading times, F_1 (1,28) = 2.88, $p = 0.10$; F_2 (1,24) = 4.53, $p < 0.05$, or total reading times, F_1 (1,28) = 1.24, $p = 0.27$; (F_2 (1,24) = 1.30, $p = 0.26$. Thus, overall, there was some (albeit limited) evidence to suggest that the effect of target-Frequency was modulated by whether or not useful target-preview information was available to the reader.

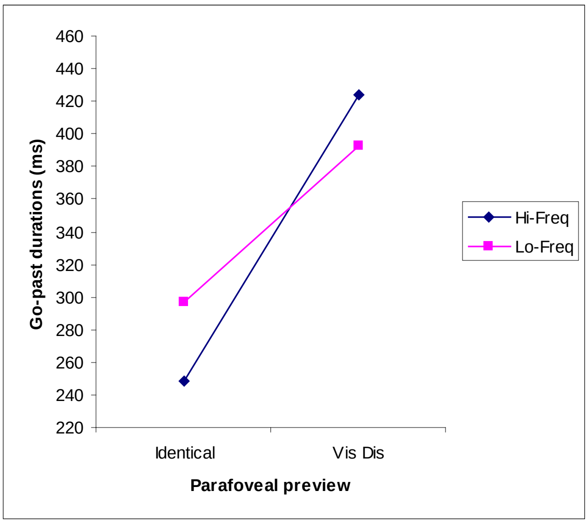


Figure 5.6. The form of the Frequency by Preview interaction in go-past durations in zone 4.

5.3.5. Analysis of zone 5-the region following the target word

Table 5.4. A range of Reading Time measures (in ms) derived from zone 5.

	Identical Preview				Visually Dissimilar Preview				Correct Preview Advantage			
Measure	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**	**HF P**	**LF P**	**HF U**	**LF U**
First Fix	234	238	256	230	274	255	248	259	40	17	-8	29
Gaze	303	236	283	303	315	259	276	324	12	23	-7	21
Go-past	337	273	389	428	398	343	396	458	61	70	7	30
Re-reading	33	37	106	125	83	83	120	134	50	46	14	9
TRT	387	338	389	444	438	351	414	444	51	13	25	0

Note: HF = High-Frequency, LF = Low-Frequency, P = Predictable, U = Unpredictable. TRT = Total Reading time.

Table 5.4 shows that the nature of the target-Preview influenced first fixation durations in zone 5, F_1 (1,28) = 15.90, $p < 0.001$; F_2 (1,24) = 8.66, $p < 0.01$, with longer inspection times when the target-Preview had been Visually Dissimilar to the target word. This effect was not significant in gaze, F_1 (1,28) = 1.72, p = 0.20; F_2

(1,24) = 1.42, p = 0.24, but there was a trend towards an effect in go-past, F_1 (1,28) = 3.73, p = 0.07; F_2 (1,24) = 7.79, p < 0.01, re-reading time, F_1 (1,28) = 14.50, p < 0.001; F_2 (1,24) = 3.21, p = 0.08, and in total reading time, F_1 (1,28) = 2.89, p = 0.10; F_2 (1,24) = 4.53, p < 0.05. Given that the Visually Dissimilar Preview was only present when the eyes were to the left of zone 4, this suggests that it continued to exert an inhibitory effect two words downstream, and that a long-range spill-over effect was obtained.

There was no continuing effect of Predictability in either first fixation durations, F's < 1, or gaze, F_1 (1,28) = 3.12, p = 0.08; F_2 < 1. However, there was a trend towards an effect in go-past, F_1 (1,28) = 19.34, p < 0.001; F_2 (1,24) = 2.25, p = 0.14, re-reading time, F_1 (1,28) = 14.50, p < 0.001; F_2 (1,24) = 3.21, p = 0.08, and total reading time, F_1 (1,28) = 14.50, p < 0.001; F_2 (1,24) = 3.21, p = 0.08, with longer inspection times following Unpredictable words. The fact that there were trends in these latter measures only, suggests that the (albeit non-significant) effects tended to be driven by re-fixations, with more time spent re-reading unpredictable words. The direction of these effects is consistent with the literature which shows greater spill-over for unpredictable words as opposed to predictable words, but presumably this related to later integrative effects, rather than an effect on the word recognition process.

The Frequency of the target word did not influence either first fixations, F_1 (1,28) = 1.61, p = 0.21; F_2 (1,24) = 1.12, p = 0.30, gaze, F_1 (1,28) = 2.54, p = 0.12; F_2 < 1, go-past, F's < 1, re-reading times, F's < 1, or total reading times, F_1 (1,28) = 1.53, p = 0.22; F_2 < 1, in zone 5. In addition, the Frequency by Preview interaction was not significant in any of the measures, all F's < 1.

5.4. General Discussion of Experiment 2

One of the aims of Experiment 2 was to address the issue of whether the joint effects of frequency and predictability are modulated by the amount of parafoveal preview information initially available to the reader. Based on research by Hand et al., it was hypothesised that if target-frequency and predictability are less likely to interact with decreasing preview information, then the interaction should disappear following a severely misspelled target-preview. The outcome was that there was no evidence at all that frequency and predictability interacted in fixation durations, an outcome which is at odds with that of Experiment 1. This difference in outcomes was not due to the different misspelled preview conditions employed since there were no frequency by predictability by preview interactions in either of the experiments. That is, in both experiments, the joint effects of frequency and predictability were not modulated by the type of preview, and therefore the amount of preview, initially available in parafoveal vision, thus providing evidence against the experimental hypothesis and also Hand et al.'s conclusions.

It should have been possible to at least obtain an interaction in the identical preview condition employed here since this condition replicated the identical preview condition employed in Experiment 1 (average launch position from the pre-target word into the target word was also similar in both experiments), yet, the interaction was not apparent here and was not apparent across both experiments. If Sternberg's (1969) Additive Factors logic can be applied to fixation durations, then the interaction in Experiment 1 does not in itself provide good evidence to suggest that frequency and predictability affect the same stage of word encoding. Instead, it appears that when taken together, experiments 1 and 2 provide evidence to suggest that frequency and predictability exert additive effects on fixations durations, an outcome which is compatible with a number of recent studies (e.g. Rayner, et al., 2004; Altarriba, et al., 1996; Lavigne, et al., 2000; Rayner, et al., 2001; Ashby, et al., 2005; Kennedy, et al., submitted), and which could either imply that the variables affect different stages or that they affect the same stage but do not interact. It should be recalled that whilst the *E-Z Reader* model predicts the latter, SWIFT does not make any predictions regarding whether the variables interact or not, although both variables are predicted to affect a lexical pre-processing stage. Thus, if it can be shown that the variables exert additive effects on fixation durations because they actually influence different stages of word-encoding, then this would suggest that the way in which either frequency or predictability effects are instantiated in both the models, is incorrect. This issue is returned to in Chapter 8.

A further aim of Experiment 2 was to re-address the issue of whether the predictability effect is the result of a process of word-prediction in which readers use a combination of contextual and parafoveal preview information to make a prediction about an up-coming word, and then subsequently confirm or disconfirm this prediction when the word is eventually fixated. If this is the mechanism underpinning the predictability effect, then it should be more difficult to obtain a predictability effect when no useful parafoveal preview information is available. The present study showed that the predictability effect, which was apparent following the identical preview, disappeared following a severely misspelled preview, suggesting that initial preview information was required in order for a subsequent predictability effect to be obtained. Thus, the present outcome is therefore compatible with a word-prediction account of predictability effects and also provides further support for Hypothesis Testing and Guessing Game models of reading. The results obtained here also suggest that the reason that a predictability by preview interaction was not obtained in the previous experiment was because the degree of the misspelling achieved in the misspelled preview condition in that experiment was not severe enough. Taken together, the results of Experiments 1 and 2 are also in-line with Balota et al.'s research which showed a predictability effect following an identical target-preview and visually similar preview but no such effect following a visually dissimilar preview.

Experiments 1 and 2 have provided evidence to suggest that the predictability effect may be one relating to word-anticipation. However, since only two levels of predictability were employed in the experiments, it was not possible to thoroughly examine the form and nature of predictability effects. In order to do this, it is necessary to employ more than two levels of predictability. Thus, in the subsequent experiment, four levels of predictability are employed, this will enable a thorough examination of the possible aetiology of predictability effects.

Chapter 6:

An investigation into the function of the relationship between word-predictability and word-processing time

6.1. Introduction

Experiments 1 and 2 provided evidence suggesting that the mechanism underpinning the predictability effect might be one relating to word-prediction. Given that only two levels of word-predictability were employed in these experiments however, means that it was not possible to gain an in-depth insight into the nature of predictability effects. The primary aim of Experiment 3 is therefore to investigate more fully the nature of predictability effects. However, it is first necessary to consider the possible mechanisms which might be driving the effect. One possibility is that the effect is driven by an interactive-activation process, similar to that proposed by McClelland and O'Regan (1981). It should be recalled that according to their model, when useful parafoveal information is available and when the context is sufficiently constrained towards a particular word, these sources of information can be combined to provide sufficient activation for a logogen to surpass its threshold. When the context is less constrained towards a particular word, many logogens will be activated and it will take longer for the correct logogen to surpass its threshold. This type of theory therefore predicts a graded effect of predictability. That is, word-recognition time will decrease as word-predictability increases. This effect is also predicted by Becker's (1976; 1980) verification model of word recognition. According to this model, a semantic set of lexical candidates is generated from the prior sentence context while a sensory set is generated via perceptual processing. The lexical candidates are compared and verified against the visual characteristics of the word, with the semantic set being verified first, if no match is found then the sensory set will be verified next. This means that the more specific the context, the smaller the semantic set and the faster the verification process.

It could be the case however, that in line with a modular theory of language processing, predictability only exerts its effect at some post-access stage. One model which is in-line with this idea is Forster's (1976; 1979) serial search model. According to this model, the process of word recognition is data-driven and sentence context can only exert an effect via post-access mechanisms. Specifically, integration of a word with the overall meaning of the sentence takes place at a post-access stage. This model might also predict a graded effect of predictability, since the less predictable the word, the more difficult it might be expected to be to integrate it with the preceding sentence context.

As discussed above, the outcome of the previous experiments reported in this thesis suggests that the predictability effect may be one relating to word-prediction or anticipation, an idea which is inherent in early models of reading such as the Hypothesis Testing and Guessing Game models (Goodman, 1970; Haber, 1978; Hochberg, 1978; Levin & Kaplan, 1970; Smith, 1971). It should be recalled that these models suggest that readers use a combination of contextual and parafoveal information to make predictions about an up-coming word and then the prediction is either confirmed or disconfirmed when the word is eventually fixated. This theory can account for the predictability effect, as presumably less predictions are generated when contextual constraint is high than when it is low, meaning that it will take less time for a match to be made between the generated lexical candidates and the correct target word when contextual constraint is high. However, in contrast to the theories previously discussed, this theory does not predict a graded effect of predictability. This is because, cloze task results show that we are only good at guessing very predictable words and that we make lots of errors when explicitly guessing less predictable words, implying that constantly predicting words during reading is likely to cause interference effects, i.e. processing penalties. Thus, the word-prediction theory predicts that predictability effects will only be obtained when predictability is high and that the function relating word-processing time and word-predictability does not follow a smooth, continuous, monotonic decreasing function but instead follows a dog-leg function (as shown in Figure 6.1). If the functional relationship is actually a strictly decreasing one (see Figure 6.2)[1], this would appear to provide evidence against a process of word-prediction and evidence for either an interactive-activation type process or a process in which contextual information is integrated at some post-lexical stage.

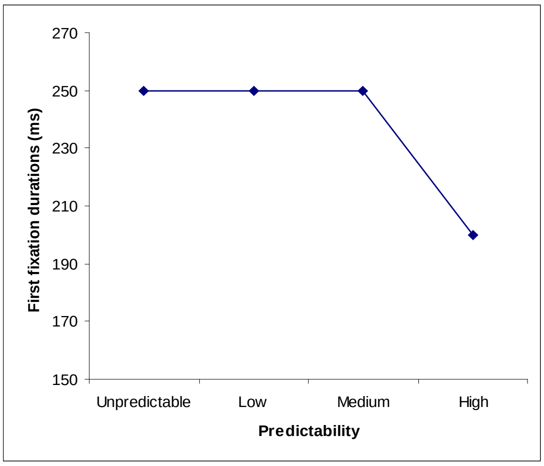


Figure 6.1. Example of non-monotonic relationship between word-predictability and word-processing time.

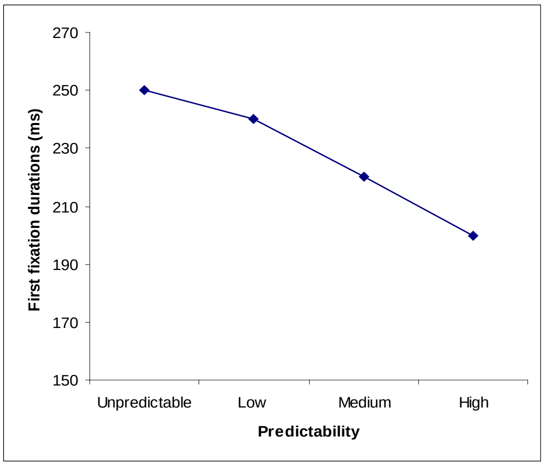


Figure 6.2. Example of monotonic relationship between word-predictability and word-processing time.

[1] For the sake of convenience, the family of functions where the function of the relationship between two variables follow either a strictly increasing or decreasing function will from henceforth be referred to as ‘monotonic’ or ‘graded’ although technically, the terminology should be ‘strictly monotonic’ or ‘strictly increasing/decreasing’. Similarly, a function which is not strictly monotonic, i.e. a dog-leg function, will be referred to as ‘non-monotonic’.

If we look at the two currently most influential models of eye-movement control (*E-Z Reader* and SWIFT) we can see that they assume a graded effect of predictability. In the *E-Z Reader* model, this is because it is assumed that as well as being a logarithmic function of a word's frequency, the time needed to complete both stages of lexical processing is linearly related to a word's predictability. The predictions of the SWIFT model are slightly more complex. According to SWIFT, fixation time is driven by word difficulty which is a logarithmic function of word-frequency and a linear function of word-predictability. However, given that the model suggests that up to approximately four words at a time may be processed in parallel, it is unclear whether SWIFT always predicts a linear relationship between inspection time and predictability on word *n*. That is, the predictability of surrounding words (which are co-processed during the fixation of word *n*), will also influence the time spent fixating word *n*, implying that a linear effect of predictability may not be obtained on *n* if the surrounding words vary in predictability. This therefore makes it difficult to determine the exact nature of the predictability effect predicted by the SWIFT model, but on the assumption that there are no necessary interactions between the predictabilities of adjoining words, then the effect, on average, would be expected to be roughly linear.

Two previous experiments have investigated whether the functional relationship between word-predictability and word-processing time is monotonic or not (see Chapter 2). It will be recalled that Rayner and Well (1996) tracked readers' eye-movements as they read sentences which were either highly-predictable, medium-predictable, or un-constrained towards a defined word. Rayner and Well found that unpredictable words took longer to process than medium- and high-predictable words while processing times on both of the latter did not differ (with equivalent mean gaze durations). The fact that the relationship between word-predictability and word-processing time was shown to be non-monotonic is incompatible with both an interactive-activation and post-lexical semantic integration account of predictability effects. However, since there was no difference in processing time between the high- and medium-predictable words, this means that there was also no good evidence for a process of word-prediction.

A similar study was carried out by Rayner, Li, Juhasz and Yan (2005). They also employed sentences which were either highly-predictable, medium-predictable or un-constrained towards a target word and examined the effect of word-predictability on the eye-movements of Chinese readers. The results of their experiment were slightly different to those obtained by Rayner and Well, since although there was no significant difference in processing time between the high- and medium-predictable words, the direction of the difference was as predicted by the models of word-recognition discussed above and *E-Z Reader*: Fixation durations decreased as predictability increased. Additionally, gaze durations were significantly longer for low-predictable, than for the medium-predictable words. Thus, overall, Rayner et al.'s (2005) study provides some evidence to suggest that the function relating predictability and fixation durations is a monotonic one. However, as discussed in Chapter 2, there are methodological problems with the materials used by both Rayner and Well and Rayner et al.: The target word and sentence context were not controlled across predictability conditions and the predictability ratings for the medium-predictable condition varied markedly with it actually comprising both low-predictable and high-predictable items. This makes it difficult to draw valid conclusions from both of these studies regarding the nature of the predictability effect.

Experiment 3 is similar to Rayner and Well's (1996) study in that it manipulates different levels of predictability, however, it incorporates better-controlled materials and four levels of predictability (High-Predictable, Moderate-Predictable, Low-Predictable and Unpredictable). Employing four levels of word-predictability enables better identification of the form of the predictability effect. In addition, unlike the previous two studies, the range of predictabilities within each condition are well-controlled and the same target word is employed across all predictability conditions. Furthermore, the words immediately surrounding the critical target word are also controlled across conditions enabling better control over the pre-target and post-target regions. Experiment 3 should therefore provide optimal conditions for examining the nature of the functional relationship between word-predictability and word-processing time. If the relationship is monotonic this will provide evidence against the suggestion that readers form predictions about up-coming words, if, as discussed above, it is assumed that there is a processing penalty for incorrect guessing. Any significant pair-wise difference in processing time that does not involve the High-Predictable condition would also provide evidence against this theory since it predicts that predictability effects should only be obtained when predictability is high.

6.2. Method

6.2.1. Participants

Thirty-two undergraduate students from the University of Dundee participated in the experiment. All were native English speakers with normal or corrected-to-normal vision and had no known language difficulties. Participants received course credit for participating.

6.2.2. Materials and Design

The experimental items were designed so that one specific target word could fit into each of 4 sentence frames. 32 item sets were constructed for use in the 4 lists (giving 128 items in total – see Appendix E). The sentence frames for each item were designed to produce a High-Predictable, a Moderate-Predictable, a Low-Predictable and an Unpredictable condition (see the example item in Figure 6.3 below). The 32 participants were randomly assigned to one of 4 counterbalanced item lists with 8 participants allocated to each. Each list included 8 items from each of the 4 predictability conditions, rotated using a counterbalanced Latin square design such that no base item occurred in more than one predictability condition within a single list.

1*a*. At the river, Karen heard quacking and saw a pair of cute brown ducks swimming along together.
1*b*. The girls noticed some beautiful swans and a pair of cute brown ducks swimming along together.
1*c*. While walking past the river, Amy saw a pair of cute brown ducks swimming along together.
1*d*. While taking in the views, the girls noticed a pair of cute brown ducks swimming along together.

Figure 6.3. An example item showing each of the four predictability conditions. The target word (underlined) was more or less predictable depending upon the preceding sentence context, example a, b, c and d are the High-Predictable, Moderate-Predictable, Low-Predictable and Unpredictable conditions respectively.

The target word which fitted into each of the four sentence frames within each item was always the same and all target words were roughly the same length (mean = 5.7 characters, range = 5 – 7). Mean target-word-frequency was 32 per million and ranged from 1 – 127 per million (according to the Kuçera & Francis, 1967, norms). The word preceding the target word was also always the same within each item. Mean pre-target-word length was 5.4 characters (range 5 – 7) and mean pre-target-word frequency was 73 per million (range 1 – 183 per million). In order to ensure a similar pattern of eye-movements across the conditions, the word prior to the pre-target word, the pre-target word and the two words following the target word were also identical across the four conditions. Total sentence length did not exceed 100 characters and sentences within item sets were matched for overall length. As well as the experimental sentences, 32 filler sentences were employed which were read by every participant. 18 comprehension questions were also employed and these were paired with some of the filler sentences and some of the experimental sentences. A further set of 8 sentences and 2 associated comprehension questions were used for practice.

Initially, five versions of 56 items were constructed and used in a cloze task in order to assess the predictability of the target words. In the cloze task (see Appendix F for task instructions), participants were presented with 60 sentence fragments and asked to continue each sentence with the first word that came into their mind. The sentence fragments were the beginning (up to the target word) of the experimental sentences considered for use in the eye-tracking experiment. These were preceded by four sentence fragments which were practice fragments. Five versions of the cloze tasks were employed since initially, 56 items (with five levels of predictability) were generated for potential use in the eye-tracking experiment, the 32 items with the best cloze task results and the four sentence frames with the most suitable predictability ratings out of the five for each item, were selected. To ensure that participants did not receive more than one sentence frame from each experimental item, 5 groups of 25 undergraduate students (125 in total) who did not take part in the eye-tracking experiment completed one of the five different versions of the cloze task. The cloze tasks took approximately 10-15 minutes to complete and participation was unpaid.

The mean probability of completing each of the sentence fragments with the target word are shown in Table 6.1 below.

Table 6.1. The mean probability of completing the High-Predictable, Moderate-Predictable, Low-Predictable and Unpredictable sentence fragments with the target word.

Predictability of sentence fragment	Mean probability of generating target	Range
High-Predictable	.91	.80 – .100
Moderate-Predictable	.67	.52 – .76
Low-Predictable	.37	.24 – .52
Unpredictable	.06	.0 – .16

The results of a repeated measures ANOVA showed that the mean ratings differed significantly as a function of predictability condition ($F(3,93) = 266.36$, $p < 0.001$) and Bonferroni t-tests confirmed that mean predictability ratings significantly differed from each other across all pairs, p's all < 0.01. A further independent group of 12 participants were asked to rate the plausibility of the experimental sentences. They were asked to rate the ordinariness or likelihood of the event being described in the sentence actually being true, on a scale of 1-7 (see Appendix C for task instructions). The participants were asked to rate the plausibility of 192 experimental sentences[2] and 72 filler sentences (36 of which were deemed plausible and 36 were deemed implausible). The task took approximately 50 minutes to complete and participants received course-credit in return. The mean plausibility ratings for each of the four experimental conditions[3] are shown in Table 6.2 below.

[2] 128 of these were employed in the present experiment, while all 192 were employed in the subsequent experiment reported in Chapter Seven.
[3] For the sentences employed in the present experiment only.

Table 6.2. The mean plausibility ratings for the High-Predictable, Moderate-Predictable, Low-Predictable and Unpredictable sentence frames.

Predictability of sentence frame	Mean plausibility of sentence frame (out of 7)	Range
High-Predictable	6.0	3.2– 6.8
Moderate-Predictable	5.8	3.2– 6.4
Low-Predictable	5.8	3.1– 6.8
Unpredictable	5.7	3.1– 6.7

A repeated measures ANOVA confirmed that the mean plausibility ratings did not differ significantly as a function of predictability condition ($F(3,93) = 1.56$, $p = 0.20$), suggesting that any effects obtained in the present experiment will not be due to sentence plausibility.

6.2.3. Apparatus

Eye movements were recorded using the same Dr. Bouis pupil-centre computation Oculomotor setup used in Experiments 1 and 2. Participants answered comprehension questions by pressing either a right or left button (for ‘yes’ or ‘no’ respectively) on an attached button-box.

6.2.4. Procedure

On arrival, participants were given oral instructions as described in Chapter 4, before being presented with a set of written instructions (see Appendix G). After reading each sentence, participants pressed a button to continue and the sentence was then replaced with either a comprehension question or dashes if these was no question, before the next sentence was presented. When presented with a comprehension question, participants had to respond ‘yes’ or ‘no’ using an attached button box. The entire experiment lasted approximately 30 - 40 minutes and participants were given two brief breaks.

6.3. Results and Discussion

For purposes of analysis, the experimental sentences were divided into six zones, shown by the back-slashes as follows:

At the river, Karen heard quacking and saw a| pair of cute| brown| ducks| swimming along| together.

zone 1 *zone 2* *zone 3* *zone 4* *zone 5* *zone 6*

Data from zone 1, which comprised the first few words of the sentence, were not analysed. In order to investigate whether the Predictability of the target word exerted any early effects, analyses were carried out on zone 2 (the three words prior to the pre-target word, e.g. ‘pair of cute’ in the example given) and on zone 3 (which was the word prior to the target word, e.g. ‘brown’ in the example given). The reason that zone 2 consisted of three words was so that the size of this zone was comparable across items (these three words were always identical within an item set). The main zone of interest was zone 4, as this contained the target word (e.g. ‘ducks’ in the example given above) and analysis of this enabled investigation into the nature of the predictability effect. In order to determine if any Predictability spill-over effects were apparent, analysis of zone 5 which comprised the two words following the target (e.g. ‘swimming along’ in the example given), was also undertaken. The size of this zone was comparable between items (the two words were always the same within each item set). Data for zone 6, which comprised the remaining words of the sentence, were not analysed.

The measures of first fixation, gaze and go-past duration, as well as re-reading time, total reading time and skipping rate were analysed for zones 2, 3, 4 and 5. Analysis employed repeated measures analyses of variances (ANOVA’s) across the four conditions, treating both participants (F_1) and items (F_2) as random variables. Pair-wise comparisons between the four Predictability conditions were performed using the Bonferroni t-test correction.

Participants clearly read the sentences carefully as overall accuracy on the comprehension questions was 92%.

6.3.1. Analysis of zone 2 - the region prior to the pre-target word

Table 6.3 below shows data for a range of inspection time measures derived from zone 2.

Table 6. 3. Mean First-Fixation duration, Go-Past duration, Gaze duration, Re-reading time and Total Reading time (in ms) derived from zone 2.

Measure	H-P	M-P	L-P	UP
First Fix	253	256	240	238
Gaze	447	463	421	474
Go-past	544	560	539	522
Re-read	96	97	118	48
TRT	565	584	546	543

Note: H-P = High-Predictable, M-P =Moderate-Predictable, L-P = Low-Predictable, UP = Unpredictable. TRT = Total Reading time.

It can be seen from Table 6.3 that the Predictability of the zone 4 target did not significantly influence go-past durations, F_1 and F_2 <1, gaze durations, F_1 (3,84) = 1.95, p = 0.14; F_2 (3,84) = 1.84, p = 0.13, or total reading times, F_1 (3,84) = 2.01, p = 0.12; F_2 (3,84) = 0.78, p = 0.51 in zone 2. However, as can be seen from the Table, and shown for clarity in Figure 6.4, the Predictability of the up-coming zone 4 target was significantly related to first fixation durations in zone 2, F_1 (3,84) = 4.68, $p < 0.01$; F_2 (3,84) = 2.65, p = 0.05. First fixation durations were longer when the Predictability of the target-word was High- or Moderate-Predictable given the sentence frame although all of the pair-wise comparisons were non-significant, p_1 and p_2 's > 0.05. Given that the zone 4 target was at this point as-yet-unfixated and at least three words down-stream, it seems unlikely that the effect could be due to an influence of the target's lexical properties. It seems more likely that it arises due to differences in the contextual constraint imposed by the sentence frame up to this point. Specifically, it could be the case that when contextual constraint is high, processing times increased due to the generation of possible lexical candidates about the up-coming target word whereas this did not occur when contextual constraint was low. Looking at the example item in Figure 6.3 (see above) it is clear that there was more contextual information about the up-coming target word in sentences *a* and *b* than in *c* and *d*. It could also be the case that when there was a lack of contextual information, readers may have pressed ahead due to uncertainty about up-coming words, thus resulting in shorter fixation durations in the less predictable conditions. Figure 6.5 provides some support for this idea as a somewhat similar effect was obtained in the measure of re-reading time, F_1 (3,84) = 4.18, $p < 0.01$; F_2 (3,84) = 2.82, $p < 0.05$, with shorter re-reading times when the up-coming target was Unpredictable given the sentence frame than when it was either Predictable, $p_1 < 0.05$;

$p_2 = 0.09$, Moderate-Predictable, p_1 and $p_2 < 0.05$, or Low-Predictable, $p_1 < 0.05$; $p_2 = 0.06$.

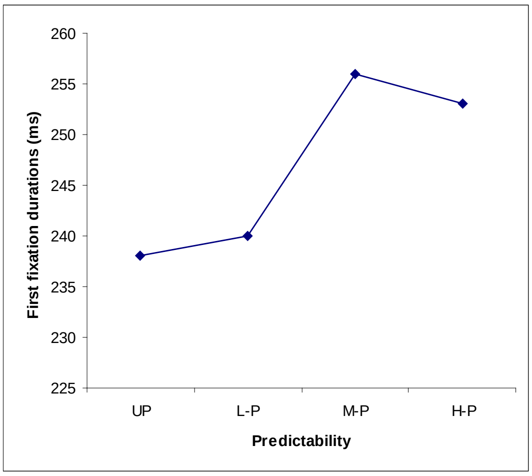


Figure 6.4. First fixation durations in zone 2.

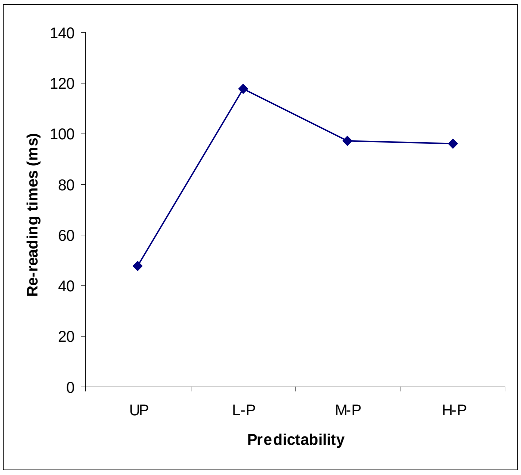


Figure 6.5. Re-reading times in zone 2.

6.3.2. Analysis of zone 3 - the pre-target word

Table 6.4. A range of Reading Time measures (in ms) derived from zone 3, together with probability of Skipping zone 3 (in characters).

Measure	H-P	M-P	L-P	UP
Skip rate	0.12	0.11	0.16	0.14
First Fix	252	248	255	258
Gaze	245	239	238	243
Go-past	304	276	273	265
Re-read	59	37	36	22
TRT	282	276	281	285

Note: H-P = High-Predictable, M-P =Moderate-Predictable, L-P = Low-Predictable, UP = Unpredictable. TRT = Total Reading time.

It is apparent that the Predictability of the zone 4 target word did not significantly influence the rate that the zone 3 pre-target word was skipped. In addition, target-Predictability did not influence first fixation durations or total reading times, all F's <1.

As shown in Figure 6.6 there was some indication of an effect of target-word predictability on go-past duration, F_1 (3,84) = 2.08, p = 0.11; F_2 (3,84) = 1.86, p = 0.14, with this increasing as the Predictability of the up-coming target increased, although none of the pair-wise contrasts were significant, p_1 and p_2's all > 0.05. This is nonetheless an interesting trend as it is in-line with the results of a previous study by Kliegl, Nuthmann and Engbert (2006; see also Kennedy, Pynte, Murray & Paul, submitted) in which it was found that single fixation durations on a currently fixated word increased as the predictability of the up-coming word increased. Kliegl et al. suggest that this outcome is the result of a cued memory retrieval process and this theory could potentially account for the findings in zone 3 here. But note, however, that these are different measures, so in order to determine whether there is compatibility between these and Kliegl et al.'s data, single fixation durations for the pre-target word were also analysed. As is apparent from Figure 6.7, the pattern in this measure is not consistent with either the go-past durations or with Kliegl et al.'s result and the difference was not at all significant, F_1 and F_2 <1.

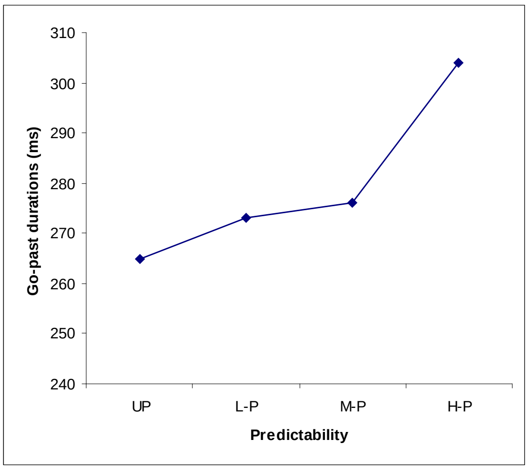


Figure 6.6. Go-past durations in zone 3.

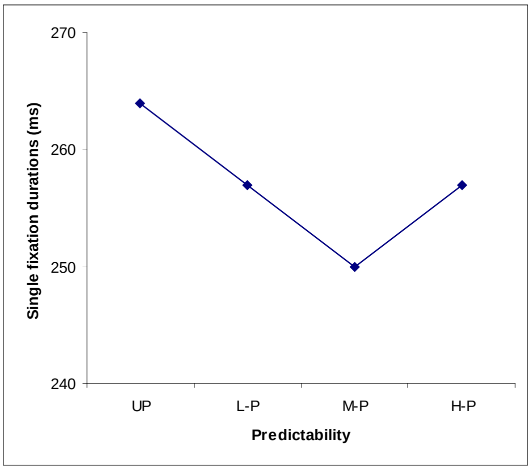


Figure 6.7. Single fixation durations in zone 3.

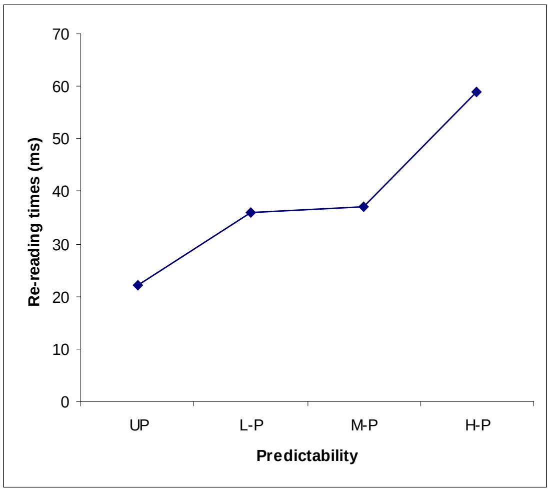


Figure 6.8. Re-reading times in zone 3.

The Predictability of the zone 4 target did not significantly influence gaze durations in zone 3, F_1 & F_2 <1, suggesting that the Predictability effect apparent in go-past was related to time spent regressing. The data from the measure of re-reading time in zone 3 shown in Figure 6.8 provides support for this suggestion, although the effect was not significant, F_1 (3,84) = 2.24, p = 0.09; F_2 (3,84) = 1.98, p = 0.12. Again, none of the pair-wise comparisons were significant, p_1 and p_2's all > 0.05.

6.3.3. Analysis of zone 4-the target word

Table 6.5. A range of Reading Time measures (in ms) derived from zone 4, together with probability of Skipping zone 4 (in characters).

Measure	H-P	M-P	L-P	UP
Skip rate	0.15	0.13	0.07	0.10
First Fix	228	231	243	249
Gaze	208	225	249	242
Go-past	229	254	282	295
Re-read	21	29	34	53
TRT	235	259	274	273

Note: H-P = High-Predictable, M-P = Moderate-Predictable, L-P = Low-Predictable, UP = Unpredictable. TRT = Total Reading time.

It is apparent from Table 6.5 that the Predictability of the target-word influenced how often this word was skipped, F_1 (3,84) = 2.92, $p < 0.05$; F_2 (3,84) = 3.38, $p < 0.05$. Consistent with the literature which suggests that predictable words are more likely to be skipped than less-predictable words, High-Predictable targets were significantly more likely to be skipped than Low-Predictable targets, p_1 and $p_2 < 0.05$. No other pair-wise comparisons were significant, including the Low-Predictable *versus* Unpredictable contrast which suggested greater skipping for Unpredictable words.

As can be seen in Figure 6.9a, there was a monotonic decrease in first fixation durations with increasing Predictability with a significant overall effect, F_1 (3,84) = 4.86, $p < 0.01$; F_2 (3,84) = 3.84, $p < 0.05$, although not all of the pair-wise comparisons were significant. First fixation durations were shorter on High-Predictable targets than on Unpredictable targets, $p_1 = 0.05$ and $p_2 = 0.06$, and shorter on Moderately-Predictable targets than the Unpredictable targets, $p_1 <0.05$ and $p_2 = 0.18$. The direction of these effects are therefore consistent with the literature. There was a similar effect in the go-past duration data (see Figure 6.9b), F_1 (3,84) = 4.68, $p < 0.01$; F_2 (3,84) = 4.16, $p < 0.01$. Go-past durations were significantly shorter on the High-Predictable targets than on the Low-Predictable targets, p_1 and $p_2 < 0.05$ and were near-significantly shorter on the High-Predictable targets than on the Unpredictable targets, p_1 and $p_2 = 0.07$. The Predictability effect in the go-past duration data for zone 4 clearly lies in the opposite direction from the effect obtained in zone 3, suggesting that different processes were operating during fixation of the target and pre-target words. Section *6.3.4.* examines whether these Predictability effects differ significantly between the two zones.

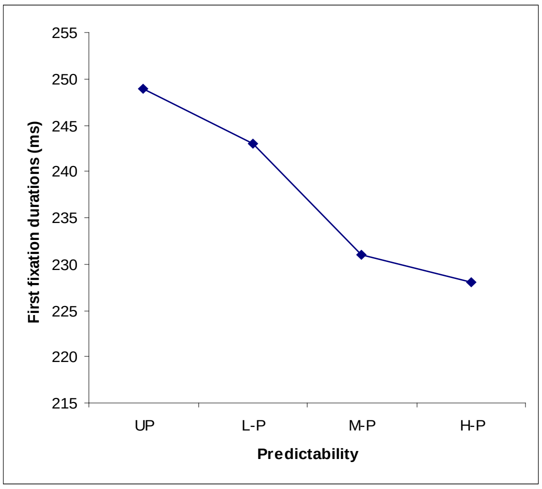


Figure 6.9a. First fixation durations in zone 4.

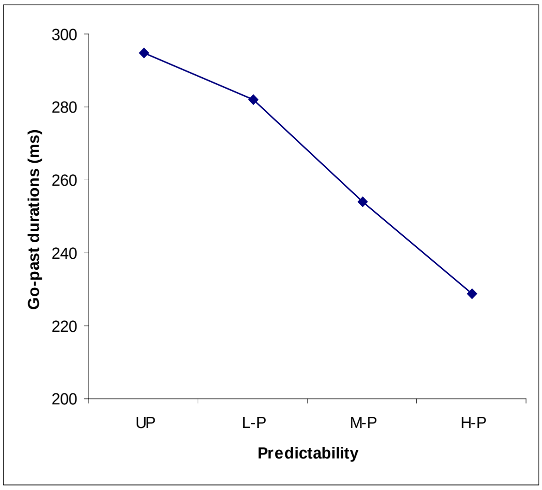


Figure 6.9b. Go-past durations in zone 4.

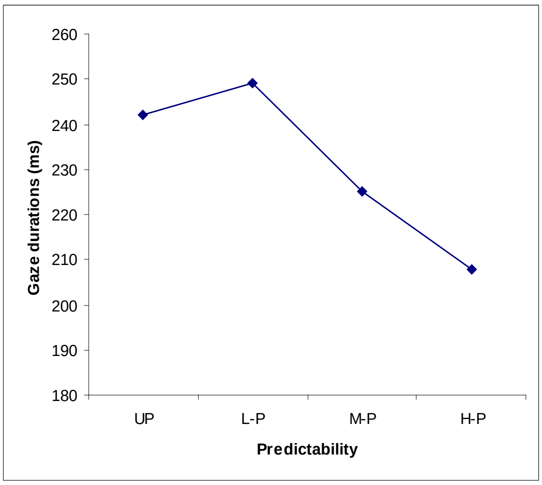


Figure 6.9c. Gaze durations in zone 4.

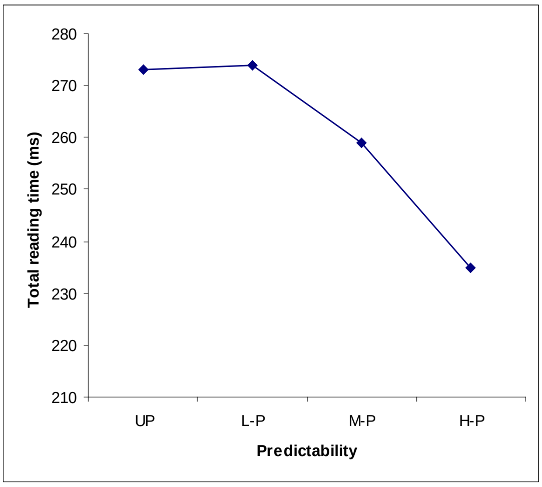


Figure 6.9d. Total reading times in zone 4.

Figure 6.9c shows that the overall effect of Predictability was also significant in the measure of gaze duration, F_1 (3,84) = 6.84, $p < 0.001$; F_2 (3,84) = 10.11, $p < 0.001$, with the High-Predictable targets processed significantly faster than both the Low-Predictable, p_1 and $p_2 < 0.01$ and Unpredictable targets, $p_1 < 0.05$ and $p_2 < 0.01$. The apparent effect in the opposite direction between the Low-Predictable and Unpredictable conditions was not significant, p_1 and $p_2 > 0.05$. There was therefore no evidence to suggest that the relationship between gaze durations and word-predictability was not monotonic. Total reading time data showed a similar pattern, F_1

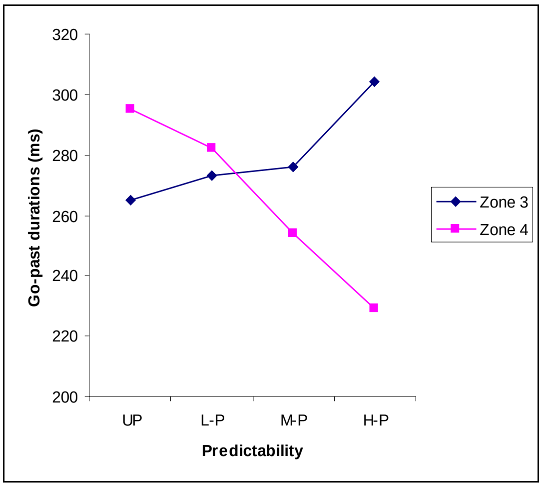
(3,84) = 4.46, $p < 0.01$; F_2 (3,84) = 5.58, $p < 0.01$, with significantly shorter times for High-Predictable than for Low-Predictable targets, p_1 and $p_2 < 0.05$.

The Predictability of the target word did not significantly influence re-reading time in zone 4, F_1 (3,84) = 1.41, $p = 0.24$; F_2 (3,84) = 1.13, $p = 0.34$.

6.3.4. Combined analysis of zones 3 and 4

In order to determine whether the Predictability effects obtained in zones 3 and 4 differed significantly, an analysis of go-past duration was conducted with Zone (3 versus 4) treated as an additional factor. Go-past durations alone were considered since the changed pattern in predictability effects was observed only in this measure and this measure also captures both early and late effects and does not 'lose' any data (see Chapter 3).

Word-predictability showed a significant interaction with Zone, F_1 (3,84) = 4.83, $p < 0.01$; F_2 (3,84) = 4.75, $p < 0.01$, see Figure 6.10. Despite the fact that the pre-target and target words were of similar length and frequency, it is apparent that inspection time on the two words differed markedly between the words for some predictability conditions: Inspection time in High-Predictable items differed significantly between zones 3 and 4, p_1 and $p_2 < 0.01$, and there was a trend towards a significant difference for the Moderate-Predictable targets, $p_1 = 0.10$; $p_2 = 0.13$. Inspection time did not differ between the two zones for either the Low-Predictable or Unpredictable items, p's > 0.05. Overall, the results seem to suggest that there was a trade-off, such that when more processing occurred before the target, less occurred on the target. As can be seen from Figure 6.11, there was no main effect of Predictability taken across both words, F_1 (3,84) = 1.07, $p = 0.37$; F_2 (3,84) = 0.89, $p = 0.55$.



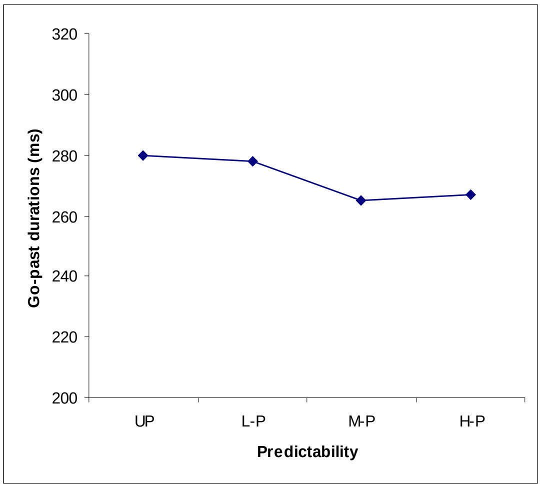


Figure 6.10. Go-past durations in zones 3 and 4. **Figure 6.11. Go-past durations averaged across zones 3 and 4.**

6.3.5. Analysis of zone 5-the region following the target word

Table 6.6. A range of Reading Time measures (in ms) derived from zone 5.

Measure	H-P	M-P	L-P	UP
First Fix	247	250	243	245
Gaze	278	297	279	294
Go-past	312	339	350	314
Re-read	34	41	72	20
TRT	377	400	370	393

Note: H-P = High-Predictable, M-P =Moderate-Predictable, L-P = Low-Predictable, UP = Unpredictable. TRT = Total Reading time.

As can be seen in Table 6.6, the Predictability of the zone 4 target-word did not influence skipping rate in zone 5, F's <1. There were also no significant spill-over effects of target-Predictability in the measures of first fixation duration, F's <1, go-past duration, F_1 (3,84) =1.33, p = 0.27; F_2 (3,84) = 1.07, p = 0.37, gaze duration, F_1 (3,84) =1.56, p = 0.20; F_2 (3,84) = 0.44, p = 0.73, nor total reading time, F_1 (3,84) = 1.27, p = 0.31; F_2 (3,84) = 1.00, p = 0.60. The only near-significant effect was in the measure of re-reading time, F_1 (3,84) =1.90, p = 0.13; F_2 (3,84) = 2.53, p = 0.06, and none of the pair-wise comparisons were significant, all p's > 0.05. Thus, there was no evidence to suggest that the less-predictable target-words caused processing difficulty on the subsequent word. Of course, the spill-over region (zone 5) in the current experiment consisted of two words rather than one but it will be recalled that these words were matched within items and the length of this region was similar between items. The fact that there were no spill-over effects, suggests that any processing ease/difficulty was manifested on the critical word itself, rather than in the post-target region. That is, since spill-over effects are often associated with the integration of the meaning of the target word into the global meaning of the sentence, the lack of spill-over effects imply that this process may have occurred during fixation of the critical word. This issue will be returned to in section *6.4*.

6.4. General Discussion of Experiment 3

The measures of inspection time on the target word in Experiment 3 provide evidence to suggest that the relationship between word-predictability and word-processing time is a monotonic one. This outcome is incompatible with the idea that the predictability effect is the result of a process of word-prediction if it is assumed that there is a penalty for generating incorrect predictions. However, it may of course be the case that readers do make predictions about up-coming words but that there is no penalty for incorrect guesses, this type of theory would potentially predict a graded effect of predictability and therefore be compatible with the current results. That is, presumably the number of predictions generated decreases as contextual constraint increases, and if there is no penalty for incorrect guesses, then it will take less time for a match to be made between the generated lexical candidates and the correct target word when contextual constraint is high than when it is low. Before any conclusions can be made regarding the nature of the predictability effect, it is necessary however, to consider the effects which were obtained prior to inspection of the target word.

It will be recalled that when the eyes fell on zone 2 and were still quite far away from the target word, processing time in this region increased as the predictability of the up-coming target word increased. Given that the target word was at least three words downstream at this point, it seems implausible that this effect arose due to the predictability of the target word per se. One possible explanation is that the effect was due to local interpretative or integration difficulty. However, this actually seems implausible given the direction of the effect. That is, if the reader experienced difficulty with integrating the words in zone 2 with the preceding sentence context, then greater processing difficulty, and therefore inflated fixation durations, might be expected when the words comprising zone 2 were embedded in less-constraining sentence contexts. This is because, the overall meaning of the preceding sentence would be less apparent in less-constraining sentence contexts. Thus, it makes sense that the reader should experience greater integration difficulty when contextual constraint is low. A more plausible explanation for the effect in zone 2 therefore, is that it was the result of word-anticipation. More specifically, it could be that when contextual constraint is high, possible target-word candidates are generated fairly early on during sentence parsing. Thus in these contexts, the inflated fixation durations reflect anticipatory processes, whereas no such process kicks in when contextual constraint is low.

When the eyes were closer to the target-word, go-past durations on the pre-target word increased as the predictability of the up-coming word increased, an effect which has previously been reported by Kliegl et al. (2006) and Kennedy et al. (submitted). There are three theories described in the literature which could account for parafoveal-on-foveal effects relating to predictability, thus it is worthwhile discussing each of these in order to determine which one can best account for the effect obtained here. The first theory relates to that of mislocated fixations, a hypothesis previously discussed in Chapters 1 and 2. It should be recalled that according to the mislocated fixation proposal (e.g. Drieghe, Rayner & Pollatsek, 2008), saccades that undershoot the intended target word could give rise to apparent parafoveal-on-foveal effects since in these cases, although fixation is on the pre-target word, it is actually the target word that is being processed. According to this theory therefore, any predictability effect obtained on the pre-target word should actually be a target-word effect. As a consequence, the mislocated fixation theory predicts that the direction of the pre-target predictability effect should be in the same (orthodox) direction as target-predictability effects. However, given that this was not the case here, means that the present data cannot be accounted for by the mislocated fixation proposal and therefore questions the explanatory power of the hypothesis.

An alternative for the pre-target predictability effect is that, contrary to the mislocated fixation proposal, it was the result of a genuine parafoveal-on-foveal influence. That is, the pre-target and target words were simply processed together. However, this is also unlikely since there was in fact no significant predictability effect across the pre-target and target words taken together. In addition, it was shown that inspection strategy on the pre-target and target words significantly differed from each other, implying that different processes were operating during the inspection of each of these words.

A further alternative for the pre-target predictability effect obtained here, is that it was the result of cued memory retrieval, a hypothesis suggested by Kliegl et al. (2006). It should be recalled from Chapter 2 that this hypothesis proposes that readers may anticipate an up-coming word (*n*) if the sentence is heavily constrained towards (*n*) and retrieve the word from memory during fixation on the prior word (*n*-1), using prior sentence context as a retrieval cue. This process would therefore result in inflated fixation durations on *n*-1. Kliegl et al. further propose that when the up-coming word is unpredictable, the eyes are shifted to the word (as if the mind is sending the eyes to have a look), resulting in shorter inspection times on *n*-1. Such an account of pre-target predictability effects provides a better explanation of the present data. That is, it can explain why an inverted pre-target predictability effect was obtained and why different processes appeared to be operating during the inspection of the pre-target and target words.

In an early draft of the paper, Kliegl, Nuthmann and Engbert initially speculated that the inverted pre-target predictability effect may be due to a process of memory retrieval encompassing anticipatory, memory and perceptual processes. Specifically, the authors suggested that the initial letters of the as-yet-unfixated predictable word (*n*) may also help to facilitate retrieval of this word during fixation on *n*-1. This version of the hypothesis suggests that the effect could critically depend upon the availability of parafoveal preview information, and it seems plausible that this may be the case. It is possible to distinguish between these two versions of the hypothesis by examining whether a pre-target predictability effect is apparent when the target-preview is not available for parafoveal processing. The next experiment investigates this issue. Experiment 4 replicates Experiment 3 by employing the same sentence frames and target words but in half of the cases, the target-preview is masked while in parafoveal vision using a pixel scrambling technique. If an effect of target-predictability is obtained on the pre-target word when the target-preview is masked, then clearly the effect does not depend upon the availability of parafoveal preview information and cannot be an effect of memory retrieval critically cued by perceptual processes.

The reading time data prior to the target-word suggests that anticipation processes operate during silent reading but in order to achieve a greater understanding of the mechanisms underpinning the predictability effect it is necessary to consider the pattern of data obtained as a whole. It has already been argued that the relationship between word-predictability and word-processing time is monotonic implying that the predictability effect is not driven by a process of word-prediction which assumes a processing penalty for incorrect guessing. A monotonic relationship would however, be compatible with either an interactive-activation type process of word recognition such as that proposed by McClelland and O'Regan (1981) or with a process of word recognition in which context influences some post-lexical stage (e.g. Forster, 1976; 1979). The fact that there were no apparent spill-over effects, effects which are usually associated with the ease or difficulty with integrating the target word into the overall meaning of the sentence, suggests that any integration may have taken place on the critical word itself. If this was the case, then the target-predictability effects could perhaps be best accounted for by a modular theory of language processing (e.g. Forster, 1979). However, it is doubtful that this theory could account for the early effects obtained here. That is, since according to the Modular theory, context can only exert an influence at some post-lexical stage[4], this would mean that both the zone 2

[4] According to both the Modular and Interactive theories, context can influence lexical access via intra-lexical priming, however, the present study does not provide a test of this.

and zone 3 effects would have to be ones of local semantic integration difficulty. However, there was no evidence to suggest this, given that fixation durations in these zones increased in high-constraining, and therefore 'easier', sentences.

As previously discussed, the type of target-predictability effects obtained here would also be compatible with a cost-free word-prediction process. There is no reason to assume that parafoveal preview information should not be used to make predictions in such a cost-free process, meaning that the outcome of Experiments 1 and 2 which showed that the predictability effect was only apparent following useful preview information, could also be explained by such a process. Moreover, if the mechanism underpinning both pre-target and target-predictability effects is fairly similar in nature, and since the pre-target effects obtained here appear to best explained by some form of anticipation process, then perhaps target-predictability effects may be best accounted for by a cost-free process of word-prediction. Since in the next experiment reported, the target-preview is masked so that only pixel information is available, means that it is possible to further investigate whether or not the target-predictability effect is the result of such a process.

Overall, it appears that some form of anticipation process may be one of the mechanisms underpinning both early and target-predictability effects. As previously discussed, whether the pre-target predictability effect can be replicated when the target-preview is masked, will help to differentiate between two possible versions of the cued memory retrieval hypothesis, and whether the target-predictability effect is only apparent following initial preview information, will provide a further test of whether the effect is due to a cost-free process of word-prediction. These issues are addressed in the next chapter.

Chapter 7:

Exploring the nature of early predictability effects

7.1. Introduction

In Chapter 6 it was shown that go-past durations on a currently fixated word increased as the predictability of the word currently in parafoveal vision increased. This effect replicated an earlier outcome obtained by Kliegl, Nuthmann and Engbert (2006; see also Kennedy, Pynte, Murray & Paul, submitted) and it will be recalled that these authors propose that the effect arises as the result of a cued memory retrieval process. Specifically, Kliegl et al. propose that when the sentence is heavily constrained towards a particular word (*n*), the reader will anticipate the up-coming word and begin to retrieve it from memory during fixation on the prior word (*n*-1). When the sentence is not constrained towards a particular word, there is no anticipation, so the eyes are instead shifted to (*n*), resulting in shorter inspection times. This process of cued memory retrieval therefore results in inflated fixation durations on a currently fixated word when the up-coming word is predictable. Such an account of inverted pre-target predictability effects is plausible given that very early effects of predictability were obtained in Experiment 3; effects which are very unlikely to have arisen due to an influence of lexical properties of the target word since this word would not have been within the readers' visual or attentional span.

As discussed in Chapter 6, Kliegl, et al. had initially speculated that the cued memory retrieval of a predictable word may also be influenced by perceptual processes. That is, they suggested that if the reader has anticipated an up-coming predictable word (*n*), and if, while in parafoveal vision, the initial letters of word (*n*) match the reader's expectation, then this information may also facilitate retrieval. If the initial letters do not match the reader's expectation, then the eyes are instead shifted to word *n*. This version of the cued memory retrieval hypothesis therefore also predicts inflated fixation durations on a currently fixated word when the up-coming word is predictable, but perhaps only, or especially, when the word is perceptually available in parafoveal vision.

Two other alternative explanations for the pre-target word effect shown in Experiment 3 were also considered (the first relating to the theory of mislocated fixations and the second relating to the idea that the foveal and parafoveal words were processed together) but each of these were rejected as being implausible. This is because, while the first theory predicts an effect in the opposite direction, there was also no evidence of a predictability effect across the pre-target and target words taken together, suggesting that the effect was also unlikely to be the result of a genuine parafoveal-on-foveal influence. The aim of Chapter 7 is therefore to test the extent to which parafoveal cueing might play a role in the sorts of predictability effect obtained on the pre-target word in the experiment reported in Chapter 6.

In order to assess the importance of parafoveal cueing, Experiment 4 replicates Experiment 3 but includes an additional condition in which the initial letters of the defined target word (while in parafoveal vision) are masked. The masking is achieved using a pixel scrambling technique. This methodology ensures that no letter information is available, which is of course crucial for discriminating between the two versions of the cued memory retrieval hypothesis, while enabling pixel density to be controlled. It is necessary to control pixel density so that readers still acquire luminosity and general configurational information without actual letter or lexical information, thus creating a ‘neutral’ parafoveal preview.

Virtually all of the previous experiments that have employed different types of parafoveal target-preview and then measured how they affect fixation time on the target word (compared to when the target word isn’t changed at all) have employed ‘non-neutral’ previews such as those that are semantically related or unrelated to a target word, or nonsense words, including those that are visually similar or dissimilar to a target (e.g. Balota, Rayner & Pollatsek, 1985). Fixation times are always shown to be faster on a target word following a correct preview than an incorrect preview (as demonstrated in Experiments 1 and 2 of this thesis, for example) but it is unclear whether this effect is due to facilitation in the correct preview condition or inhibition in the incorrect preview conditions. However, the pixel scrambling manipulation should provide a neutral base-line for examining the nature of preview effects and also for discriminating between the two versions of the cued memory retrieval hypothesis. The contingent-boundary procedure (as employed in Experiments 1 and 2) is utilised so that the target-mask is only ever available in parafoveal vision. When the eyes cross an invisible boundary between the defined pre-target and target words, the masked target is restored to its correct format.

In the previous chapter, it was further proposed that the monotonic relationship obtained between target-word-predictability and fixation duration could perhaps be best explained by a cost-free process of word-prediction which assumes no penalty for incorrect guessing. This is because, although the form of the target-predictability effect obtained could also be explained by either an interactive-activation type process of word recognition (e.g. McClelland & O’Regan, 1981) or by a process of semantic integration which occurs at some post-access lexical stage (e.g. Forster, 1979), the predictability effects obtained prior to the target word appeared to be related to word-anticipation processes. That is, if the mechanisms underpinning both pre-target and target predictability effects are similar in nature, then word-anticipation processes were able to explain the pattern of predictability effects obtained as a whole. Of course, pre-target and target-predictability effects may be driven by different mechanisms, thus it is now necessary to clarify whether the target-predictability effect is best explained by a cost-free process of word-anticipation and the present study provides optimal conditions for investigating this. That is, if it is the case that readers use a combination of contextual and parafoveal information to make predictions about up-coming words, then it will be impossible to make predictions in the unmasked preview condition employed here.

If in the present experiment, a predictability effect (either inverted or otherwise) is obtained on the pre-target word in the masked condition, then this would provide evidence against the version of the cued memory retrieval hypothesis which predicts that pre-target predictability effects are dependent on target-preview information being available for parafoveal processing.

An orthodox (non-inverted) predictability effect on the pre-target word in either the unmasked or masked conditions would provide evidence against both versions of the cued memory retrieval hypothesis, since both versions suggest that fixation times should be inflated when up-coming words are predictable. However, an inverted predictability effect in the unmasked condition would replicate Experiment 3 and provide support for memory retrieval cued by the initial letters of the parafoveal target word. An inverted effect, with no interaction between predictability and preview would provide evidence for cued memory retrieval which does not critically depend upon parafoveal processing of the predictable word.

As previously discussed, an interactive-activation type process of word recognition, a post-lexical semantic integration process and a cost-free process of word-anticipation, would all predict a graded effect of predictability on the target word, and since this type of effect was obtained in the previous experiment, it is expected that a similar effect will be obtained here in the unmasked condition. If the effect is due to a cost-free process of word-prediction, then a predictability by preview interaction should be apparent, with an effect of predictability in the unmasked preview condition but no effect in the masked condition.

It should be recalled from the previous chapter that the current implementation of predictability effects in the *E-Z Reader* model also assumes that the function relating word-predictability and word-processing time is a monotonic one. From this viewpoint there is no reason to assume that the form of the predictability effect should change with a lack of parafoveal preview information. Overall processing times on the target should of course be inflated because according to the model, since there is no parafoveal preview information, there will be no preview benefit; meaning that processing of the target will not begin until the target is actually fixated, but the magnitude and nature of any predictability effect should not be affected.

In Chapter 6 it was suggested that the SWIFT model is also likely to predict a monotonic relationship between word-predictability and word-processing time if it is assumed that there is no necessary interaction between the predictabilities of adjoining words and the target word. Again, from this stance, there is no reason to assume that the form of the effect should change when the target is masked while in parafoveal vision. However, it would be predicted that the absolute size of the predictability effect should be larger in the masked condition. This is because the model assumes that lexical processing is distributed and that predictability is a lexical access effect. That is, the target-mask will prevent any parafoveal pre-processing which would otherwise normally take place while the eyes are to the left of the target word, meaning that when the word is eventually fixated, the effect should be larger.

If, as predicted by the SWIFT model, there is a larger predictability effect in the masked condition than in the unmasked condition, then a predictability by preview type interaction may be apparent on the target word. This would of course be driven by a difference in the overall magnitude of the predictability effect between preview conditions rather than differences in form. The *E-Z Reader* model, on the other hand, predicts that neither the form nor the magnitude of the predictability effect should alter across the preview type conditions and therefore that predictability by preview type interactions should not be apparent.

7.2. Method

7.2.1. Participants

Forty undergraduate students from the University of Dundee participated in the experiment. All were native English speakers with normal or corrected-normal vision and had no known language difficulties. Participants received either course credit or £5 for participating.

7.2.2. Materials and Design

48 items were employed. These consisted of the 32 items employed in Experiment 3 as well as an additional 16 from those generated for potential use in Experiment 3 (see Appendix E for a full list of the items and the previous chapter for an example item). Additional items were employed in order to increase item power, given the greater number of counterbalanced item files required in this design. This resulted in a set of items which had the same general characteristics as those used in Experiment 3. Table 7.1 shows that the mean length and word-frequency of the target and pre-target words were similar in both experiments.

Table 7.1. Mean (and range of) word lengths (in characters) and word frequencies for target and pre-target words employed in Experiments 3 and 4.

Experiment	Target length (mean)	Target length (range)	Pre-target length (mean)	Pre-target length (range)	Target freq (mean)	Target freq (range)	Pre-target freq (mean)	Pre-target freq (range)
Three	5.7	5-7	5.4	5-7	32	1-127	73	1-183
Four	5.8	5-7	5.4	5-7	35	1-127	86	1-834

Both the predictability and plausibility ratings for the 48 items employed in the present experiment were established in the previous experiment. It can be seen from Table 7.2 that the mean predictability ratings for the target words employed here did not significantly differ from those reported in Chapter 6 ($F(1,78) = 0.01$, $p = 0.92$), while the mean predictability ratings for the items employed in the present experiment, differed significantly as a function of predictability condition ($F(3, 141) = 1070.79$, $p < 0.001$). Bonferroni t-tests confirmed that mean predictability ratings significantly differed from each other across all pairs, p's all < 0.01.

Table 7.2 further shows that the mean plausibility ratings for the items employed here did not significantly differ from those reported in Chapter 6 ($F(1,78) = 0.07$, $p = 0.80$). Additionally, the mean plausibility ratings for the items employed here did not differ significantly as a function of predictability condition ($F(3, 141) = 1.69$, $p = 0.17$), suggesting that any effects obtained in the present experiment are unlikely to be due to measured sentence plausibility.

Table 7.2. The mean probability of completing the High-Predictable, Moderate-Predictable, Low-Predictable and Unpredictable sentence fragments with the target word and the mean plausibility ratings for each of the four types of sentence frames for Experiments 3 and 4.

Predictability of sentence fragment	Experiment	Mean probability of generating target	Range	Mean plausibility of sentence frame (out of 7)	Range
High-Predictable	Three	.91	.80 –.100	6.0	3.2 – 6.8
	Four	.90	.80 –.100	5.9	3.2 – 6.8
Moderate-Predictable	Three	.67	.52 – .76	5.8	3.2 – 6.4
	Four	.65	.52 – .76	5.8	3.2 – 6.6
Low-Predictable	Three	.37	.24 – .52	5.8	3.1 – 6.8
	Four	.35	.20 – .52	5.8	3.1 – 6.8
Unpredictable	Three	.06	.0 – .16	5.7	3.1 – 6.7
	Four	.05	.0 – .16	5.6	2.9 – 6.7

Given that there were an increased number of experimental items in the present experiment, the number of filler sentences and comprehension questions employed were also increased (to 48 and 32 respectively).

It will be recalled that the experimental items were designed so that one specific target word could fit into each of 4 sentence frames. In total, 392 items were employed (48 item sets x 8 lists). The reason that 8 lists were employed is because an additional factor (‘Preview’) was included in the present experiment so that in half of the experimental conditions, the target word was masked while in parafoveal vision. The masking was achieved using a pixel scrambling technique (see Apparatus section). The 40 participants were randomly assigned to one of 8 counterbalanced item lists with 5 participants allocated to each. Each list included 48 items (6 from each of the 4 'Unmasked' predictability conditions and 6 from each of the 4 'Masked' predictability conditions). Items were rotated across lists following a counterbalanced design such that no base item occurred in more than one predictability or preview condition within a single item list.

7.2.3. Apparatus

Eye movements were recorded using the same Dr. Bouis pupil-centre computation Oculomotor employed in previous experiments. The general procedure employed was the same except that a pixel scrambling technique was also utilised. This technique enabled the target to be masked while in parafoveal vision. Specifically, for every target word, the pixels for each of its letters were scrambled so that scrambled pixels replaced letter information. This technique therefore maintains luminosity and pixel density information but prevents letter and lexical information being retrieved. The eye-movement contingent change from 'mask' to 'no-mask' was achieved by writing directly to the video memory of the graphics control card and was not dependent on the refresh cycle of the display. With a screen refresh rate of 100Hz together with 2ms eye movement sampling, this resulted in an average display change delay of approximately 7ms and a delay never exceeding 13ms. The contingent procedure ensured that the target-word mask (if present) was displayed only while the eyes were to the left of an invisible boundary located after the last letter of the pre-target word. To ensure strict comparability between display conditions, the contingent procedure was also employed in the unmasked preview conditions, as well as in the filler sentences (in which the target letters were replaced by themselves).

7.2.4. Procedure

On arrival, participants were given oral instructions as described in Chapter 4. They were then given a set of written instructions (see Appendix H) which were the same as those given in Experiment 3, the only difference related to the increased time required for the experiment (the present experiment lasted approximately 45 minutes). All other aspects of the experimental procedure were the same as Experiment 3 except for the fact that the contingent boundary procedure was also employed in the present experiment.

7.3. Results and Discussion

Similarly to Experiment 3, the experimental sentences were divided into six zones and various measures of inspection time and fixation position were analysed for four critical zones – the region prior to the pre-target word, the pre-target word, the target word and the region following the target word. Analyses employed 2 x 4 mixed analyses of variances (ANOVA's), treating both participants (F_1) and items (F_2) as random variables. The first factor 'Preview' was a within-subjects factor and had two levels ('Masked' and 'Unmasked'), while the second factor 'Predictability' was identical to that manipulated in Experiment 3.

Overall accuracy on the comprehension questions was 97% suggesting that participants read the sentences carefully.

7.3.1. Analysis of zone 2 – the region prior to the pre-target word

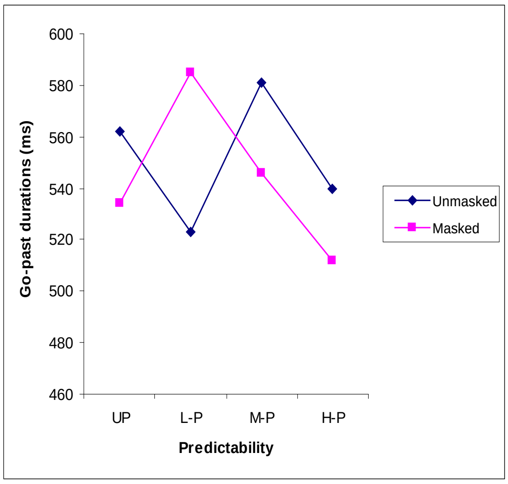
Table 7. 3. Mean First-Fixation duration, Go-Past duration, Gaze duration, Re-reading time and Total Reading time (in ms) derived from zone 2.

	Unmasked Preview				Masked Preview			
Measure	**H-P**	**M-P**	**L-P**	**UP**	**H-P**	**M-P**	**L-P**	**UP**
First Fix	253	256	242	248	251	254	256	237
Gaze	453	461	476	481	445	469	478	482
Go-past	540	581	523	562	512	546	585	534
Re-read	87	120	47	81	66	78	106	52
TRT	554	586	566	601	514	578	603	562

Note: H-P = High-Predictable, M-P =Moderate-Predictable,
L-P = Low-Predictable, UP = Unpredictable.
TRT = Total Reading time.

It can be seen from Table 7.3 that first fixation durations in zone 2 were not significantly influenced by either the Predictability of the zone 4 target word, F_1 $(3,96) = 2.25$, $p = 0.99$; F_2 $(3,120) = 1.22$, $p = 0.31$, or whether the target was masked or not, F_1 $(1,32) = 0.00$, $p = 0.95$; F_2 $(1,40) = 0.04$, $p = 0.84$, and there was no significant Predictability by Preview interaction, F_1 $(3,96) = 2.22$, $p = 0.09$; F_2 $(3,120) = 1.70$, $p = 0.17$. These outcomes are logical given that the target word was at least three words downstream during the first fixation of zone 2.

There were also no significant effects of Predictability or Preview, and no significant Predictability by Preview interaction in the gaze duration data, all F's < 1, and no overall effects of Predictability, F_1 $(3,96) = 1.77$, $p = 0.16$; F_2 $(3,120) = 0.37$, $p = 0.78$, or Preview, F_1 $(1,32) = 0.24$, $p = 0.63$; F_2 $(1,140) = 0.53$, $p = 0.52$, in go-past duration. However, a Predictability by Preview interaction was significant in go-past, F_1 $(3,96) = 3.71$, $p < 0.05$; F_2 $(3,120) = 3.00$, $p < 0.05$. It is apparent from Figure 7.1 that the interaction is driven by the difference in the effect of Preview on go-past durations for the Low-Predictable items, although the pair-wise comparison between the Unmasked and Masked conditions for these items was in fact not significant, p_1 and $p_2 > 0.05$.



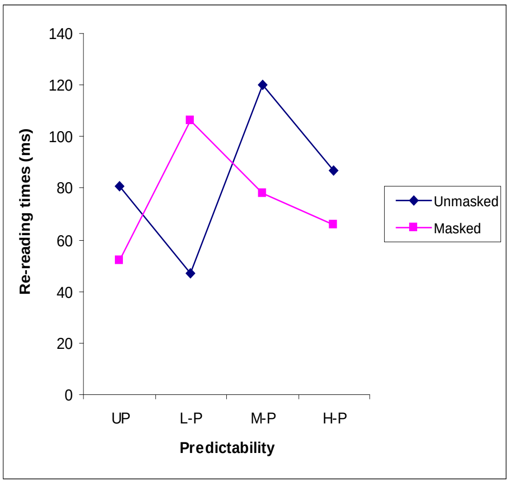


Figure 7.1. Go-past durations in zone 2.

Figure 7.2. Re-reading times in zone 2.

Given that there were no effects in the gaze duration data, it is likely that the interaction present in go-past is related to the time spent re-reading. Analysis of the re-reading time data confirmed this with no significant effect of target-Predictability, F_1 (1,32) = 0.32, p = 0.58; F_2 (1,40) = 0.31, p = 0.59, or whether the target was Masked or not, F_1 (3,96) = 1.40, p = 0.25; F_2 (3,120) = 0.69, p = 0.56, while the Predictability by Preview interaction was significant, F_1 (3,96) = 4.18, $p < 0.01$; F_2 (3,120) = 4.77, $p < 0.01$, see Figure 7.2 above. Again, the interaction appears to be driven by a difference in re-reading times between the Unmasked and Masked conditions for the Low-Predictable items, but again the pair-wise comparison was non-significant, p_1 and $p_2 > 0.05$.

The fact that Predictability by Preview interactions were apparent in both go-past and re-reading time is plausible given that these are relatively late measures and would have been picked up on fixations made towards the end of zone 2. That is, towards the end of zone 2, the target-preview would have been in the readers' attentional span and could have plausibly exerted an effect on processing strategy in this zone. The form of the interactions are however, somewhat enigmatic and are not easily interpretable. In contrast to the previous experiment, there was no evidence for the idea that readers generate possible lexical candidates early on during sentence parsing when contextual constraint is high. This is because, while in the previous experiment, fixation durations in zone 2 were longer in High-Constraining sentences, this did not appear to be the case here. Thus, the most parsimonious conclusion to be drawn regarding the nature of the present zone 2 interactions is that readers simply read the words comprising zone 2 more quickly when the sentence was low-constrained towards the target word and the target was unmasked.

There were no reliable effects of Predictability, F_1 (3,96) = 4.40, $p < 0.01$; F_2 (3,120) = 0.91, $p = 0.56$, or Preview, F_1 (1,32) = 0.90, $p = 0.65$; F_2 (1,40) = 1.80, $p = 0.18$, in the total reading time data. In addition, the Predictability by Preview interaction was not significant, F_1 (3,96) = 2.28, $p = 0.08$; F_2 (3,120) = 2.22, $p = 0.09$.

7.3.2. Analysis of zone 3 – the pre-target word

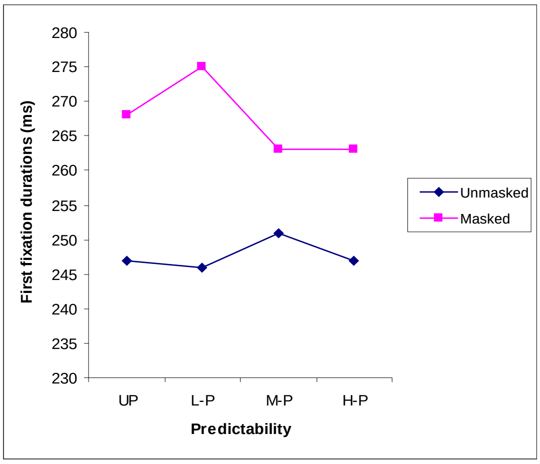
The means for each of the inspection time measures and the skipping rate for zone 3 are shown in Table 7.4. Neither the Predictability of the zone 4 target, nor whether this word was Masked or not, influenced how often the pre-target word was skipped, all F's < 1.

Table 7. 4. A range of Reading Time measures (in ms) derived from zone 3, together with probability of Skipping zone 3 (in characters).

Measure	Unmasked Preview				Masked Preview			
	H-P	M-P	L-P	UP	H-P	M-P	L-P	UP
Skip	0.14	0.15	0.15	0.12	0.16	0.1	0.14	0.12
First Fix	247	251	246	247	263	263	275	268
Gaze	237	239	231	236	248	265	263	280
Go-past	255	297	264	270	274	301	283	299
Re-read	18	58	33	34	26	36	20	20
TRT	256	288	270	283	318	340	377	372

Note: H-P = High-Predictable, M-P =Moderate-Predictable,
L-P = Low-Predictable, UP = Unpredictable.
TRT = Total Reading time.

The presence of a mask affected first fixation duration in this region, with longer fixations in the Masked condition, F_1 (1,32) = 27.78, $p < 0.001$; F_2 (1,40) = 16.08, $p < 0.001$, but this measure showed no effect of Predictability, F_1 (3,96) = 0.79, p = 0.51; F_2 (3,120) = 1.59, p = 0.19, and no interaction between Predictability and Preview, F_1 (3,96) = 0.32, p = 0.81; F_2 (3,120) = 0.60, p = 0.62, see Figure 7.3. A similar pattern was shown in gaze duration with longer gaze durations in the Masked condition than in the Unmasked condition, F_1 (1,32) = 19.53, $p < 0.001$; F_2 (1,40) = 13.65, $p < 0.001$, and no overall effect of Predictability, F_1 (3,96) = 0.77, p = 0.52; F_2 (3,120) = 1.07, p = 0.37, or significant Masking by Predictability interaction, F_1 (3,96) = 0.68, p = 0.57; F_2 (3,120) = 0.66, p = 0.58, see Figure 7.4.



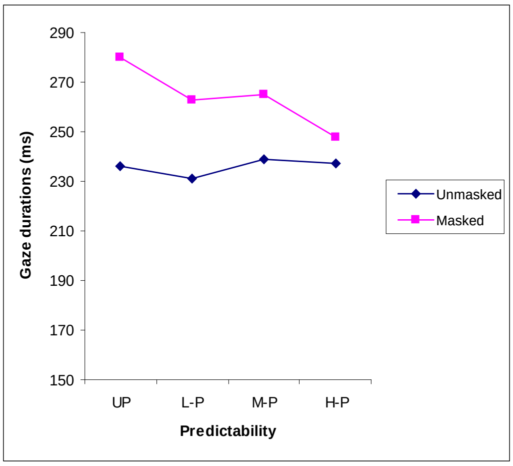


Figure 7.3. First fixation durations in zone 3.

Figure 7.4. Gaze durations in zone 3.

Unlike Experiment 3, there was no significant effect of target-Predictability on go-past durations, F_1 (3,96) = 1.95, p = 0.13; F_2 (3,120) = 1.27, p = 0.29. There was also no significant effect of Preview, F_1 (1,32) = 2.20, p = 0.14; F_2 (1,40) = 2.94, p = 0.09, and no hint of an interaction between Predictability and Preview, F_1 (3,96) = 0.22, p = 0.88; F_2 (3,120) = 0.57, p = 0.64.

In order to determine whether this null Predictability effect differed reliably from the near-significant Predictability effect obtained on the pre-target word in Experiment 3, a combined ANOVA was carried out on the go-past duration data for the pre-target word in Experiment 3 and for the pre-target word in the Unmasked condition of Experiment 4. It can be seen from Figure 7.5 that there were no main effects of Experiment, F_1 (1,70) = 0.36, p = 0.55; F_2 (1,78) = 1.81, p = 0.18, or Predictability, F_1 (3,210) = 0.90, p = 0.44; F_2 (3,234) = 0.85, p = 0.47. However, the Experiment by Predictability interaction was near-significant, F_1 (3,210) = 2.34, p = .07; F_2 (3,234) = 1.84, p = 0.14, while the main effect of Predictability was close to significant in Experiment 3, F_1 (3,84) = 2.08, p = .11; F_2 (3,84) = 1.86, p = 0.14, it was not significant (and was different in form) in the Unmasked condition in this Experiment,

F_1 (3,96) = 1.44, p = 0.23; F_2 (3,120) = 1.39, p = 0.25. More specifically, the form of the Predictability effect appeared to differ between Experiments particularly in the case of the High-Predictable items.

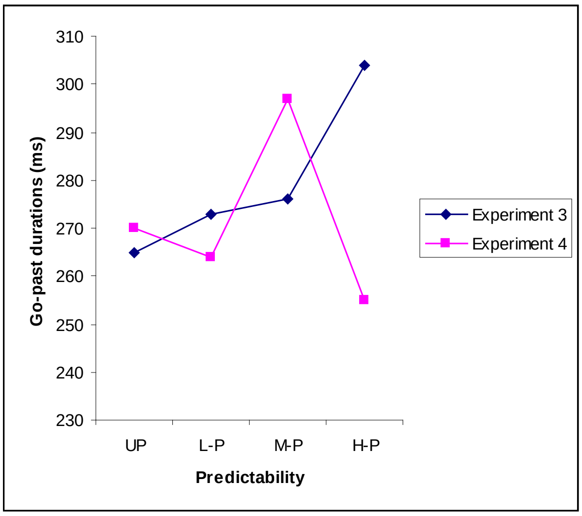


Figure 7.5. Go-past durations in zone 3 in Experiments 3 and 4.

It is not immediately apparent why the form of the Predictability effect should differ between Experiment 3 and the present Experiment. It is therefore worthwhile investigating the go-past duration data in more depth using a more sophisticated statistical technique in order to determine whether the inverted pre-target Predictability effect obtained in Experiment 3 can be replicated and to determine the factor or factors that may have contributed to the subtle differences shown here. Thus *lmer* analyses will be pursued for the go-past duration data, as well as for the first fixation and gaze duration data, as this technique can take into account multiple sources of variation simultaneously and enables Predictability to be treated as a continuous variable rather than a categorical variable, meaning that it is ideal for testing for linearity. If the inverted predictability effect can be replicated in the measure of go-past then further support for a process of cued memory retrieval will be obtained. The reason that the first fixation and gaze duration data are also further explored is because despite the non-significant Predictability by Preview interactions in these data, the pattern of fixations seemed to diverge between the Unmasked and Masked Preview conditions for the less-predictable items, revealing what appeared to be a trend towards a non-inverted Predictability effect in the Masked condition, while there appeared to be no Predictability effect at all in the Unmasked condition. If it can be shown via *lmer* analysis that there is in fact a Predictability effect in the Masked condition and that there is no effect in the Unmasked condition, then this would provide evidence against the perceptually-cued version of the cued memory retrieval hypothesis (for the reasons set out in the *Introduction*). Section 7.3.5 reports the results of *lmer* analyses carried out on the first fixation, go-past and gaze duration data for the pre-target word.

The re-reading data for the pre-target word showed a fairly similar pattern to that of the go-past duration data as there was no influence of Preview, F_1 (1,32) = 1.57, p = 0.22; F_2 (1,40) = 1.60, p = 0.21, and no significant Predictability by Preview interaction, F_1 (3,96) = 0.64, p = 0.60; F_2 (3,120) = 1.02, p = 0.39, although there was a near-significant effect of Predictability, F_1 (3,96) = 2.25, p = 0.09; F_2 (3,120) = 2.32, p = 0.08.

Figure 7.6 shows that consistent with all other inspection time data for zone 3, total reading times were significantly longer when the up-coming target was Masked than when it was Unmasked, F_1 (1,32) = 48.37, p < 0.001; F_2 (1,40) = 55.73, p < 0.001. In addition, the overall effect of target-Predictability was significant, F_1 (3,96) = 3.38, p < 0.05; F_2 (3,120) = 2.59, p = 0.05, with total reading times increasing as up-coming Predictability decreased, although the only near-significant pair-wise comparison was between the High-Predictable and Unpredictable items, $p_1 < 0.05$ and $p_2 = 0.08$. This effect did not differ between Preview conditions, and the Predictability by Preview interaction was not significant, F_1 (3,96) = 1.53, p = 0.21; F_2 (3,120) =2.01, p = 0.11. Although the direction of the Predictability effect obtained in total reading time lies in contrast to that predicted by both versions of the cued memory retrieval hypothesis, the total reading time data do not provide a good test of the hypotheses since it includes fixations from points where the reader has gone past the pre-target word.

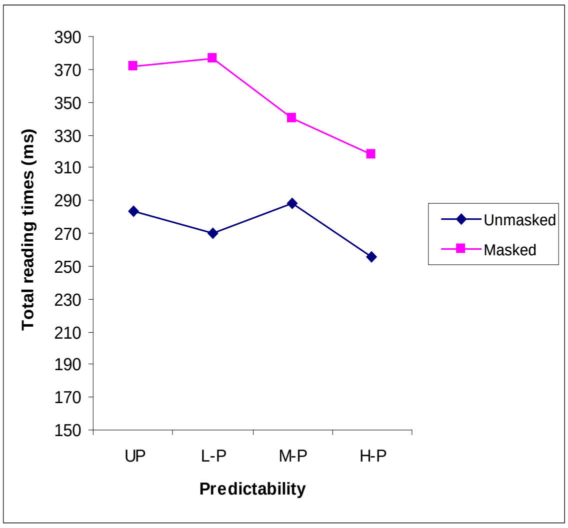


Figure 7.6. Total reading times in zone 3.

7.3.3. Analysis of zone 4 – the target word

Table 7. 5. A range of Reading Time measures (in ms) derived from zone 4, together with probability of Skipping zone 4 (in characters).

Measure	Unmasked Preview				Masked Preview			
	H-P	M-P	L-P	UP	H-P	M-P	L-P	UP
Skip	0.14	0.15	0.1	0.12	0.02	0.05	0.04	0.03
First Fix	237	225	244	241	319	319	316	341
Gaze	222	212	251	241	367	362	386	378
Go-past	236	248	270	295	450	419	482	454
Re-read	14	36	19	54	84	57	96	76
TRT	243	234	272	280	438	423	452	453

Note: H-P = High-Predictable, M-P = Moderate-Predictable, L-P = Low-Predictable, UP = Unpredictable. TRT = Total Reading time.

It is apparent from Table 7.5 that the target word was significantly more likely to be skipped when it had been available for parafoveal processing than when it had not, F_1 (1,32) = 57.38, p < 0.001; F_2 (1,40) = 78.58, p < 0.001. This outcome is compatible with both the *E-Z Reader* model which suggests that words are skipped because they have been processed parafoveally, and also with the SWIFT model in which some skipping takes place as a result of prior parafoveal processing. There was no overall effect of target-Predictability on the rate that the target was skipped, F_1 (3,96) = 1.77, p = 0.16; F_2 (3,120) = 1.24, p = 0.30, which is a little surprising given the assumption in both models that predictability facilitates lexical retrieval. There was also no significant Predictability by Preview interaction, F_1 (3,96) = 1.31, p = 0.27; F_2 (3,120) = 0.99, p = 0.60.

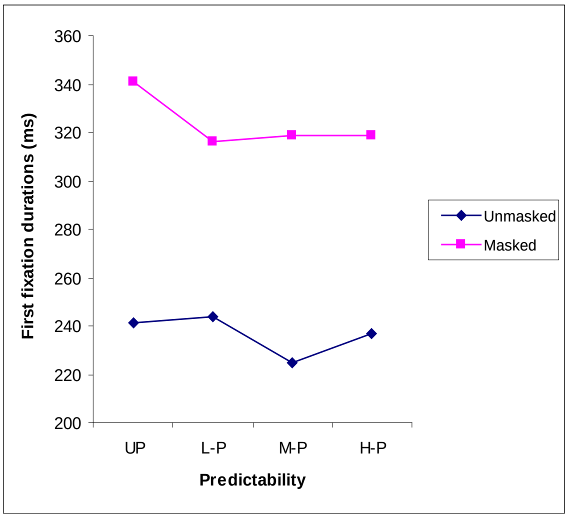


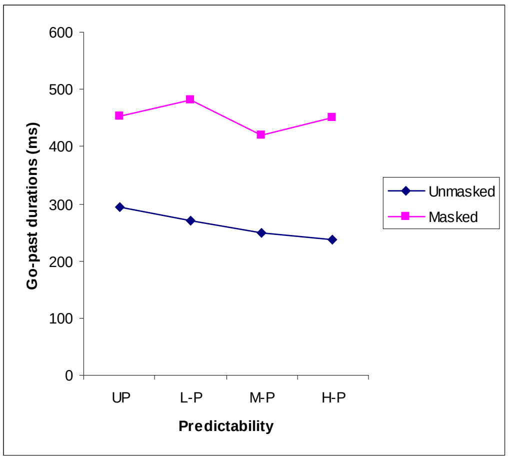
Figure 7.7. First fixation durations in zone 4.

As can be seen from Figure 7.7, first fixation durations were significantly shorter when the target word had not been masked while in parafoveal vision, F_1 (1,32) = 92.64, p < 0.001; F_2 (1,40) = 260.96, p < 0.001, with an apparent preview benefit obtained in the Unmasked condition. There was also a near-significant effect of

Predictability in the first fixation duration data, F_1 (3,96) = 2.36, p = 0.08; F_2 (3,120) = 3.23, $p < 0.05$, however, all of the pair-wise comparisons (averaged across Preview conditions) were non-significant, p_1 and p_2's > 0.05. The Predictability by Preview interaction was also near-significant, F_1 (3,96) = 2.30, p = 0.08; F_2 (3,120) = 2.29, p = 0.08. Further investigation revealed that the Predictability effect was near-significant in the Unmasked condition, F_1 (3,96) = 3.28, $p < 0.05$; F_2 (3,120) = 1.85, p = 0.14, although none of the pair-wise comparisons between the Predictability conditions were significant, p_1 and p_2 's > 0.05. The Predictability effect for the Masked items was also close to significant, F_1 (3,96) = 2.06, p = 0.11; F_2 (3,120) = 3.13, $p < 0.05$, but again, none of the pair-wise comparisons were significant, p_1 and p_2's > 0.05. Overall, it can be argued that Figure 7.7 shows that neither the magnitude nor the form of the (near-significant) Predictability effects differed between Preview conditions.

Given that the form of the effect in the Unmasked condition appears to differ from that obtained in Experiment 3, the data from other measures of inspection time will next be examined in order to further investigate whether the function relating word-predictability and inspection time is monotonic.

Similarly to the first fixation duration data, there was a significant effect of Preview in both go-past, F_1 (1,32) = 77.66, $p < 0.001$; F_2 (1,40) = 386.53, $p < 0.001$, and gaze, F_1 (1,32) = 130.93, $p < 0.001$; F_2 (1,40) = 431.74, $p < 0.001$, see Figures 7.8 and 7.9 respectively.



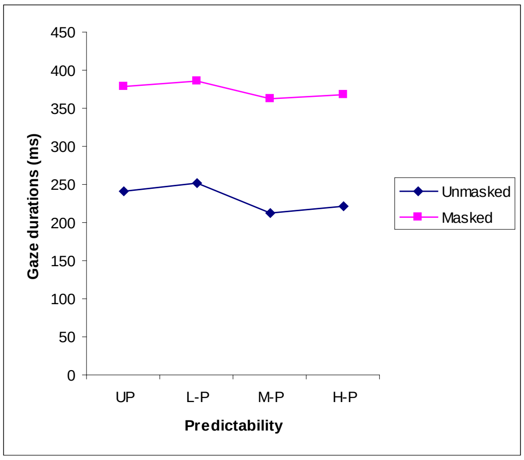


Figure 7.8. Go-past durations in zone 4.

Figure 7.9. Gaze durations in zone 4.

The main effect of Predictability was also significant in both go-past, F_1 (3,96) = 4.52, $p < 0.01$; F_2 (3,120) = 3.38, $p < 0.05$, and gaze, F_1 (3,96) = 5.09, $p < 0.01$; F_2 (3,120) = 4.01, $p < 0.01$. The Moderate-Predictable items were processed faster than the Low-Predictable items (in the data averaged across both Preview conditions), in both go-past, $p_1 < 0.05$; $p_2 = 0.16$, and gaze, p_1 and $p_2 < 0.05$. In the go-past data, the direction of the Predictability effect in the Unmasked condition was as predicted: Go-past durations on the target decreased as target-Predictability increased. In gaze, inspection times in the Unmasked condition were longer for less predictable items.

There was no evidence to suggest that the magnitude of the Predictability effect differed significantly between the Preview conditions as the Predictability by Preview interaction was not significant in either go-past, F_1 (3,96) = 1.76, $p = 0.16$; F_2 (3,120) = 1.15, $p = 0.33$, or gaze duration, F_1 (3,96) = 0.21, $p = 0.89$; F_2 (3,120) = 0.25, $p = 0.86$. The data thus far, therefore provide evidence against the idea that the predictability effect is due to a cost-free process of word-prediction.

The re-reading time data from the target word was also examined as it was expected that more time would be spent re-reading from the target word when no parafoveal preview information for the target had been available. The statistics confirmed this, F_1 (1,32) = 10.57, $p < 0.01$; F_2 (1,40) = 31.07, $p < 0.001$. The overall Predictability effect was non-significant, F_1 (3,96) = 0.95, $p = 0.58$; F_2 (3,120) = 0.95, $p = 0.58$, however the Predictability by Preview interaction was near-significant, F_1 (3,96) = 3.08, $p <$ 0.05; F_2 (3,120) = 2.47, $p = 0.06$, and it is clear from Figure 7.10 that the pattern of re-reading times for the Unmasked condition lay in contrast to that obtained for the Masked condition. Further analyses revealed that while there was no significant Predictability effect in the Masked condition, F_1 (3,96) = 1.52, $p = 0.21$; F_2 (3,120) = 1.01, $p = 0.39$, the effect was significant in the Unmasked condition, F_1 (3,96) = 2.73, $p < 0.05$; F_2 (3,120) = 3.37, $p < 0.05$. Although none of the pair-wise comparisons for the items in the Unmasked condition were significant, p_1 and p_2 > 0.05, it can be suggested that, on average, more time was spent re-reading from the target word when the target was less predictable.

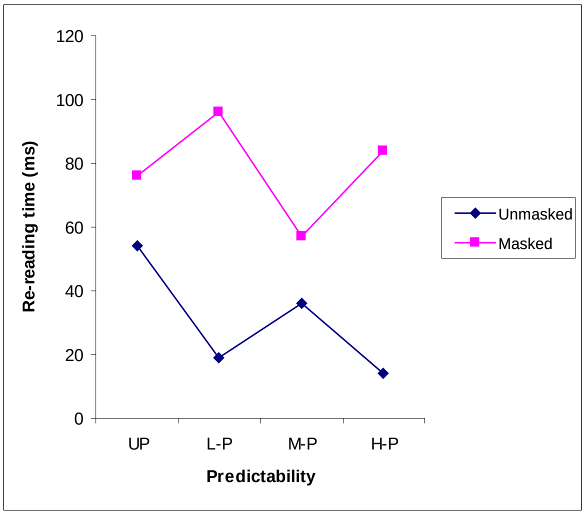


Figure 7.10. Re-reading times in zone 4.

Similarly to the data from all other measures of inspection time taken on the target word, a significant effect of Preview was obtained in the total reading time data, F_1

(1,32) = 121.26, $p < 0.001$; F_2 (1,40) = 465.02, $p < 0.001$. There was also a main effect of Predictability, F_1 (3,96) = 4.11, $p < 0.01$; F_2 (3,120) = 4.39, $p < 0.01$. Figure 7.11 shows that total reading times were significantly shorter for the Moderate-Predictable items than for the Unpredictable items, p_1 and $p_2 < 0.05$, while the form of the effect looks similar to that obtained in go-past duration. The Predictability by Preview interaction was not significant, F_1 (3,96) = 0.28, $p = 0.84$; F_2 (3,120) = 0.28, $p = 0.84$.

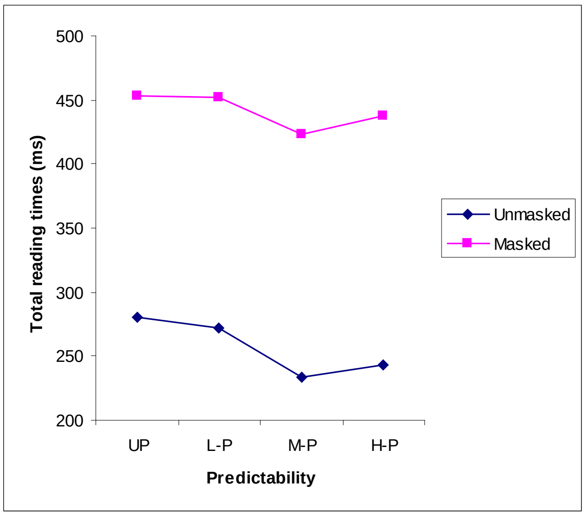


Figure 7.11. Total reading times in zone 4.

Overall, the findings from the measures of inspection time on the target word have provided solid evidence to suggest that a preview benefit was obtained when a preview of the target had been available. Predictability effects were also obtained. The go-past data revealed that inspection time decreased as predictability increased, while first fixations and gaze durations were generally shorter for more predictable words than for less predictable words, thus it is argued that the data provide evidence to suggest that the function relating word-predictability and processing time is monotonic. This outcome therefore replicates that of Experiment 3, however, there are some differences between the two sets of results. The first difference relates to the magnitude of the predictability effect, with larger effects in Experiment 3. The second relates to the form of the effect: Although it has been argued that evidence for a monotonic relationship between word-predictability and word-processing time was obtained in this experiment, the effects were not as clear-cut as they were in Experiment 3. It is clear, however, that the slight differences in both the form and the magnitude of the effects obtained here and in Experiment 3 do not appear to be due to the presence of the target-Mask. This is because, the bulk of the evidence suggests that neither the form nor the magnitude of the Predictability effect were influenced by the nature of the preview initially available in parafoveal vision.

In order to further explore the form of the predictability effects obtained in the present experiment, it was relevant to further analyse the first fixation, go-past and gaze duration data via *lmer* analyses. As previously discussed, these analyses can test for linearity. They can also simultaneously take into account other sources of variation, thus whether or not measured sentence plausibility contributes towards the predictability effect was explored. Further investigation into whether or not the predictability effect was modulated by the nature of the target-preview was also investigated. Section 7.3.6 reports the results of *lmer* analyses conducted on selected inspection time data for the target word.

7.3.4. Analysis of zone 5 – the region following the target word

Table 7.6. A range of Reading Time measures (in ms) derived from zone 5.

Measure	Unmasked Preview				Masked Preview			
	H-P	**M-P**	**L-P**	**UP**	**H-P**	**M-P**	**L-P**	**UP**
Skip	0.15	0.13	0.1	0.11	0.15	0.13	0.13	0.13
First Fix	250	255	251	265	257	266	265	253
Gaze	291	308	301	311	301	319	319	290
Go-past	320	329	336	345	335	379	394	356
Re-read	33	21	35	34	35	63	75	66
TRT	348	393	382	420	394	408	426	399

**Note: H-P = High-Predictable, M-P =Moderate-Predictable,
L-P = Low-Predictable, UP = Unpredictable.
TRT = Total Reading time.**

From Table 7.6 it can be seen that there was little influence of either Predictability or Preview, and no Predictability by Preview interaction in either skipping rate, first fixation duration or gaze duration for zone 5, all F's < 1.

There was an effect of target word masking on go-past durations in zone 5 with longer go-past durations when the target word had been Masked, F_1 (1,32) = 6.23, $p < 0.05$; F_2 (1,40) = 6.35, $p < 0.05$. It is likely that this Preview effect arose from the time spent re-reading since this effect was not apparent in gaze. The re-reading time data did in fact follow the same general pattern: More time was spent re-reading in zone 5 when the target word had been Masked than when it had been Unmasked, F_1 (1,32) = 10.48, $p < 0.01$; F_2 (1,40) = 10.50, $p < 0.01$.

There was no effect of Predictability in either go-past, F_1 (3,96) = 1.63, p = 0.19; F_2 (3,120) = 0.86, p = 0.54, or re-reading time, (3,96) = 1.29, p = 0.28; F_2 (3,120) = 0.79, p = 0.50, and no Predictability by Preview interaction in either go-past, F_1 (3,96) =

1.02, $p = 0.39$; F_2 $(3,120) = 0.69$, $p = 0.56$, or re-reading time, F_1 $(3,96) = 1.18$, $p = 0.32$; F_2 $(3,120) = 0.90$, $p = 0.55$.

Total reading times in zone 5 were also (near-significantly) longer when the target had been Masked than when it had been Unmasked, F_1 $(1,32) = 3.52$, $p = 0.07$; F_2 $(1,40) = 3.16$, $p = 0.08$, but again there was no Predictability effect, F_1 $(3,96) = 3.00$, $p < 0.05$; F_2 $(3,120) = 1.63$, $p = 0.19$, or Predictability by Preview interaction, F_1 $(3,96) = 2.36$, $p = 0.08$; F_2 $(3,120) = 1.36$, $p = 0.26$.

Overall, the zone 5 results do not provide any evidence of spill-over effects of Predictability, but they do show that the target-mask exerted a 'long-duration' effect on inspection time strategy. The latter effect is likely to be due to the fact that no preview benefit was obtained in the Masked condition, thus resulting in more time spent looking back towards the target when target-word information was eventually available.

7.3.5. Lmer analysis of Experiment 4

It will be recalled that the above analyses have resulted in a number of marginal main effects and interactions. A good way to further investigate the nature of these effects is to use LMER. This statistical procedure has a number of advantages, including the fact that it allows by-subjects and by-items effects to be treated separately but simultaneously. It also takes into account multiple sources of variation. Thus, given that plausibility ratings for each of the present experimental items were collected, using *lmer* provides the perfect opportunity for investigating whether sentence plausibility exerts any influence in this experiment and whether effects of predictability are related to those of plausibility. An additional benefit of using *lmer* is that it enables continuous variables to be treated as such, instead of being treated as discrete categorical variables as is the case with ANOVA. This means that in the following analyses, predictability can be treated as a continuous variable, allowing further investigation into whether the effect is linear or not. An additional benefit of *lmer* is that it enables data-sets to be restricted based on specific criteria. For example, in the up-coming results, before analysis, the data-set was conditioned so that data were not selected when gaze duration was more than 1500ms. This was done because close examination of the data revealed that there were a number of excessively long gaze durations in the data-set skewing the data-distribution. Restricting the data-set excluded these outliers.

The analyses were carried out in the linear-mixed effects regression model (*lmer*) framework, using the *lme4* package (Bates & Sakar, 2006) for the *R* system for statistical computing (R Development Core Team, 2006). The zones analysed were zones 3 (the pre-target word) and 4 (the target word). *Lmer* analysis of these zones enabled further investigation into whether any reliable effects of Predictability and Preview, and Predictability by Preview, were apparent, as well as investigation into the potential influence of sentence Plausibility. Thus, the independent variables were Predictability, Preview, Plausibility and Predictability by Preview in zone 3. In zone 4, the same variables were employed in an initial set of analyses, while a second set of analyses employed Predictability, Preview, Plausibility and the Skipping rate of zone 3 as independent variables (for reasons discussed below in *section 7.3.7*). First fixation, go-past and gaze duration were the dependent variables in both the zone 3 and zone 4 analyses. Participants and Items were treated as random factors. Significance is estimated from tables of the *t* statistic assuming df $= \infty$ (i.e. values > 2.0 significant at p = 0.05).

7.3.6. Lmer analysis of zone 3

Lmer analysis of the first fixation and go-past duration data in which Predictability, Preview, Plausibility and Predictability by Preview were entered as fixed effects showed a similar pattern to that obtained in the analyses of variance (correlations between the set of independent variables are given in Appendix I). That is, first fixations were shorter when the Preview of the up-coming target was available than when it was not (β = 27.27, S.E. = 7.05, t = 3.87), while this effect was not significant in go-past (β = 22.93, S.E. = 17.73, t = 1.29). There was also no effect of Predictability in either first fixations (β = 0.04, S.E. = 0.08, t = 0.52), or go-past (β = 0.00, S.E. = 0.21, t = 0.01), and no Predictability by Preview interaction in either first fixations (β = - 0.17, S.E. = 0.12, t = -1.46) or go-past (β = -0.14, S.E. = 0.30, t = -0.49). There was also no evidence to suggest that sentence Plausibility influenced either first fixation durations (β = 1.46, S.E. = 2.88, t = 0.51) or go-past durations (β = 1.51, S.E. = 7.29, t = 0.21).

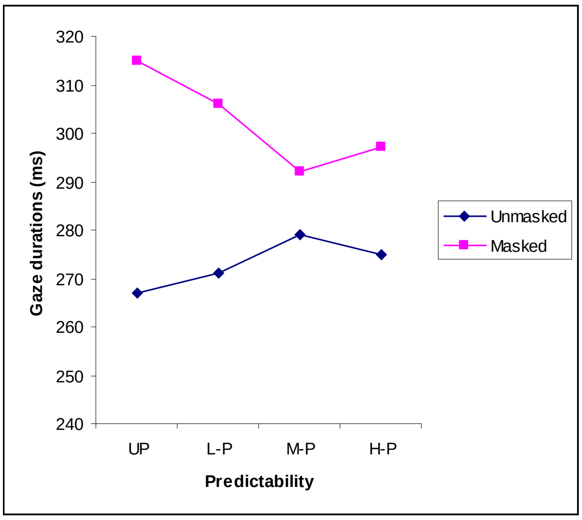


Figure 7.12. Gaze durations on the pre-target word.

The gaze duration data also showed no effect of Plausibility ($\beta = 2.84$, S.E. = 4.31, t = 0.66) nor an overall effect of Predictability ($\beta = 0.09$, S.E. = 0.13, t = 0.72). However, similarly to the first fixation duration data, an effect of Preview was obtained ($\beta = 48.26$, S.E. = 10.62, t = 4.54) and additionally, the hint of the Predictability by Preview interaction, apparent in Figure 7.4 above, was significant following *lmer* analysis ($\beta = -0.40$, S.E. = 0.18, t = -2.22), see Figure 7.12 above. In a model which still included Plausibility and Predictability but only for Masked items, there was a significant effect of Predictability: Gaze durations generally decreased as the Predictability of the up-coming word increased ($\beta = -0.32$, S.E. = 0.15, t = -2.13). Possible reasons for this effect are proposed in section *7.4*. In this model, Plausibility was still non-significant ($\beta = 2.69$, S.E. = 6.75, t = 0.40). In contrast, and in-line with the version of the cued memory retrieval hypothesis which critically depends upon parafoveal perceptual processing, when the data-set was restricted to Unmasked items only, gaze duration seemed to generally decrease as the Predictability of the up-coming word decreased, although the Predictability effect was not significant ($\beta = 0.09$, S.E. = 0.10, t = 0.87). The effect of Plausibility was also non-significant in this model ($\beta = 4.20$, S.E. = 4.74, t = 0.89). Thus there was no evidence at all to suggest that sentence Plausibility influenced processing strategy on the pre-target word, suggesting that plausibility is not the cause of the early predictability effect.

The finding of a Predictability by Preview interaction in these analyses, suggests that the pre-target predictability effect was dependent upon whether a preview of the target was available or not. However, since there was only a slight hint of a Predictability effect in the Unmasked condition, while there was a significant effect in the Masked condition, this suggests that the effect was dependent upon the target-preview *not* being available. The possible processes captured by the interaction are discussed in section *7.4*.

7.3.7. Lmer analysis of zone 4

In the initial analyses, Predictability, Preview, Plausibility and Predictability by Preview were entered as fixed effects. Consistent with the ANOVA results, there were highly significant effects of Preview in first fixation (β = 89.53, S.E. = 8.30, t = 10.79), go-past durations (β = 165.70, S.E. = 20.62, t = 8.04), and gaze durations (β = 115.38, S.E. = 11.42, t = 10.10): Inspection times were shorter following the Unmasked Preview.

The Predictability by Preview interactions were also non-significant in first fixation (β = -0.09, S.E. = 0.14, t = -0.64), go-past durations (β = 0.10, S.E. = 0.35, t = 0.28), and gaze durations (β = 0.08, S.E. = 0.19, t = 0.44). Consistent with the ANOVA results, this suggests that the Predictability effects were not modulated by the nature of the prior parafoveal preview, and were therefore not the result of a cost-free process of word-prediction.

Target-predictability did not significantly influence first fixation duration (β = -0.08, S.E. = 0.10, t = -0.78), although there was a hint of an effect in both go-past (β = -0.39, S.E. = 0.26, t = -1.51), and gaze (β = -0.25, S.E. = 0.14, t = -1.74). The fact that the target-Predictability effects were not significant in these analyses suggests that sentence plausibility contributed towards some of the effect obtained via analysis of variance. Having said this, there were no significant effects of Plausibility in either first fixation (β = -1.34, S.E. = 3.30, t = -0.41), go-past durations (β = -9.85, S.E. = 8.19, t = -1.20), or gaze durations (β = 1.89, S.E. = 4.60, t = 0.41). It was therefore necessary to next conduct a number of exploratory post-hoc *lmer* analyses in order to determine under which conditions the predictability effect was significant and what factors might contribute to the effect.

The outcome of the exploratory analyses was that the Predictability effect was near-significant (β = -0.13, S.E. = 0.07, t = -1.78) in a model in which first fixation duration was the dependent variable and Predictability, Preview, Plausibility and Skipping rate (of the pre-target word) were the fixed effects (the correlations between the set of independent variables are given in Appendix J). First fixation durations generally decreased as predictability increased, an outcome which is more in-line with the ANOVA results. In this model, there was still no effect of sentence Plausibility (β = -1.30, S.E. = 3.29, t = -0.39) while a significant effect of Preview was apparent (β = 85.06, S.E. = 4.59, t = 18.53), outcomes which are consistent with the *lmer* results reported above. There was no effect of whether the pre-target word had been skipped or not (β = -0.95, S.E. = 6.73, t = -0.14). Despite this null outcome, it appeared that the predictability effect on fixation duration may only be apparent when skipping status of the pre-target word accounts for some of the variance. It was therefore necessary to next determine whether this effect generalised across other measures of inspection time.

In order to further explore whether the effect of target-predictability was significant when skipping status of the pre-target word accounted for some of the variance, and if so, what the nature of the relationship between these two effects on target-word processing strategy might be, two further sets of analyses were undertaken. In these analyses, Preview and sentence Plausibility were still included in the models and go-past and gaze durations were the dependent variables respectively.

The analyses revealed that similarly to the first fixation durations data, there was no effect of sentence Plausibility in either the go-past ($\beta = -9.41$, S.E. = 8.02, $t = -1.17$), or gaze duration ($\beta = 2.06$, S.E. = 4.56, $t = 0.45$) data, while there was a significant effect of Preview in both go-past ($\beta = 172.44$, S.E. = 11.25, $t = 15.33$), and gaze ($\beta = 120.36$, S.E. = 6.26, $t = 19.21$). A significant effect of Skipping zone 3 was also obtained in both the go-past duration ($\beta = 109.04$, S.E. = 16.45, $t = 6.63$), and gaze duration ($\beta = 46.04$, S.E. = 9.17, $t = 5.02$) data, with longer inspection times on the target when the pre-target had been skipped. Furthermore, the effect of Predictability was also significant in go-past ($\beta = -0.36$, S.E. = 0.18, $t = -2.07$), and in gaze ($\beta = -0.22$, S.E. = 0.10, $t = -2.19$), providing support for the hypothesis that Predictability effects in fixation durations are only apparent when skipping status of the pre-target word accounts for some of the variance. In order to interpret this finding, it was necessary to next determine whether the predictability effect was apparent when the pre-target word had been fixated or when it had been skipped[5].

Further analyses were carried out on both the go-past and gaze duration data-sets examining effects when the pre-target word had been fixated and when it had not. When the pre-target word had not been skipped, as would be predicted, there was a highly significant effect of Preview in both go-past ($\beta = 164.31$, S.E. = 11.48, $t = 14.31$), and gaze ($\beta = 119.29$, S.E. = 6.28, $t = 18.98$), while there was still no evidence to suggest that Plausibility influenced either go-past ($\beta = -8.79$, S.E. = 8.28, $t = -1.06$), or gaze ($\beta = 3.46$, S.E. = 4.49, $t = 0.77$). However, the effect of Predictability was near-significant in go-past ($\beta = -0.32$, S.E. = 0.18, $t = -1.81$), and significant in gaze ($\beta = -0.26$, S.E. = 0.10, $t = -2.63$). Figures 7.13 and 7.14 show that inspection times

[5] There was a trend towards a Skipping (zone three) x Predictability interaction in gaze when the interaction was also included in the model (B = 0.33, S.E. = 0.28, t = 1.19

decreased as Predictability increased. In order to determine whether fixation of the pre-target word was a pre-requisite for obtaining a Predictability effect on the subsequent word, it was necessary to next investigate whether or not the effect was significant when the pre-target word had been skipped.

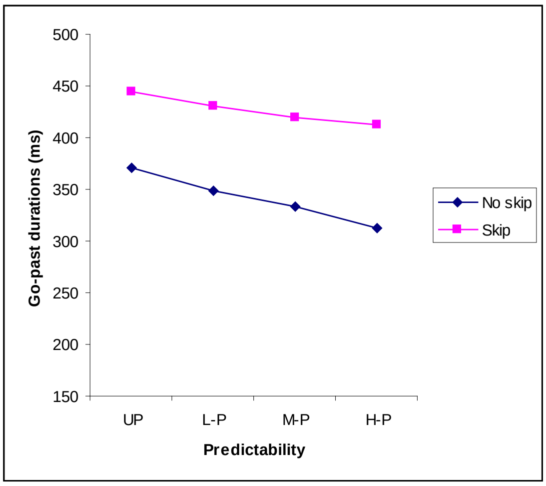


Figure 7.13. Go-past durations in zone 4 dependent on whether the pre-target word had been skipped or not.

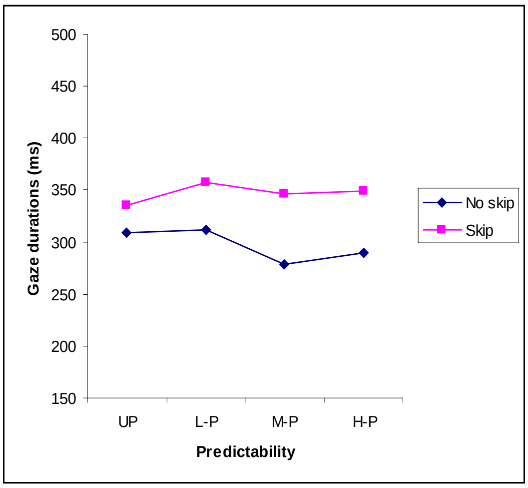


Figure 7.14. Gaze durations in zone 4 dependent on whether the pre-target word had been skipped or not.

When the pre-target word had been skipped, the effect of Preview was still apparent in both go-past (β = 217.40, S.E. = 39.34, t = 5.53) and gaze (β = 121.38, S.E. = 23.40, t = 5.19). This means that the nature of the target-preview exerted a very early effect on processing strategy since the decision to skip the pre-target word would have been made while the eyes were fixating the region prior to the pre-target word. This outcome is compatible with the results reported earlier in the chapter which suggested that the nature of the target-preview exerted an effect in the region prior to the pre-target word. There was no hint of a Predictability effect in either go-past (β = -0.54, S.E. = 0.63, t = -0.86), or gaze (β = 0.27, S.E. = 0.38, t = 0.71), suggesting that the Predictability effect was only significant when the pre-target word had not been skipped. Lastly, there was also no effect of sentence Plausibility in either go-past (β = -17.77, S.E. = 24.22, t = -0.73) or gaze (β = -6.35, S.E. = 15.88, t = -0.40).

There was less power in the analysis of the ‘skip’ data-set because in the model in which the pre-target word was skipped, there were only 236 observations, while there were 1418 observations in the ‘no skip’ data-set. However, Figures 7.13 and 7.14, above, suggest that there was little or no effect of Predictability in the ‘skip’ data-set, hence it is unlikely that a Type 2 error occurred. Overall, the *lmer* analyses carried out on the target word data therefore suggest that the Predictability effect is only apparent when the previous word has been fixated.

The fact that the target-predictability effect was modulated by skipping status of the pre-target word likely reflects individual differences in reading behaviour. That is, if in some cases, the eyes press ahead of where integration has got to, then this may produce more word-skipping and delayed effects of predictability. More specifically, if in some cases, the meaning of the words comprising zone 2 had already been integrated into the meaning of the sentence, and the pre-target word was subsequently skipped, this may have caused integration of the pre-target and target words to subsequently be delayed.

7.4. General Discussion of Experiment 4

The primary goals of this study were to determine whether pre-target predictability effects can be explained by a process of cued memory retrieval and to explore whether predictability effects on a critical word can be explained by a cost-free process of word-prediction. The overall aim was to determine whether the mechanism underpinning all types of predictability effects is one relating to word-anticipation.

Before discussing the primary issues addressed by this study, it is worthwhile discussing a separate issue raised in the *Introduction* relating to the nature of the parafoveal preview benefit that is well-documented in the reading literature (e.g. Blanchard, Pollatsek, & Rayner, 1989; Morris, Rayner, & Pollatsek, 1990; Rayner, Well, Pollatsek & Bertera, 1982; Schroyens, Vitu, Brysbaert & d'Ydewalle, 1999). It was suggested that the masking manipulation employed in this experiment could be used to resolve the issue of whether parafoveal preview benefit is the result of either the facilitation of correct preview information or inhibition from incorrect preview information. This is because, here in the masked preview condition, there was no incompatible preview information to create any inhibitory effects, suggesting that if a preview benefit was obtained in the unmasked condition then this would have to be due to facilitation in this condition. The present study did obtain a preview benefit in the unmasked condition, and therefore provides evidence to suggest that the preview benefit shown in previous studies is due to the facilitation of correct preview information as opposed to inhibition from incorrect preview information. This finding is helpful in aiding our understanding of eye-movement behaviour during reading since it provides solid evidence to suggest that parafoveal preview information facilitates word recognition.

In the previous experiment there was some evidence to suggest that the mechanism underpinning very early predictability effects may be one relating to word-anticipation. This is because, first fixation durations in zone 2 were inflated when the up-coming target word was predictable given the preceding sentence context, an outcome which would be compatible with the idea that readers generate possible lexical candidates when the sentence is heavily constrained towards a particular word or sub-set of words. In the present study there was no evidence for such a process, and since the effect obtained here in zone 2 was a "late" effect, suggests that in further contrast to the previous experiment, the effect was at least partly driven by the predictability of the target word per se since the target word could have plausibly been within the readers' visual or attentional span. Given the discrepancies with the outcome and likely cause of the early predictability effects obtained here and in the previous experiment, it is necessary to further explore whether there is any evidence for systematic early effects of predictability and whether these effects are related to lexical access of the target word. This issue is returned to later in this section.

One of the primary goals of this study was to distinguish between two different versions of the cued memory retrieval hypothesis, since the experiment reported in Chapter 6 provided evidence consistent with a process of cued memory retrieval. It should be recalled that Kliegl et al. (2006) propose that readers can anticipate an up-coming word (*n*) if the sentence is heavily constrained towards it and will retrieve the as-yet-unfixated word from memory during fixation of the prior word (*n*-1), using prior sentence context as a retrieval cue. Additionally, it was speculated that perceptual processes may also be critically involved in such a cued memory retrieval process. That is, if the reader has anticipated an up-coming predictable word (*n*), and if, while in parafoveal vision, the initial letters of the predictable word match the reader's expectation, then the reader may begin to retrieve the word from memory during fixation of the preceding word (*n*-1), using both the initial letters of the predictable word (*n*), and the prior sentence context as retrieval cues. Both versions of this hypothesis predict that the process of retrieving the predictable word (*n*) from memory results in inflated inspection times on a prior word (*n*-1). In the present study, gaze durations on the pre-target word increased as the predictability of the up-coming target word decreased, but this effect was only apparent when the target word was masked while in parafoveal vision. This effect therefore cannot be due to a process of cued memory retrieval which critically involves parafoveal access to perceptual properties of the upcoming word since there was no parafoveal information available to act as a cue and since the direction of the effect is opposite to that predicted by the hypothesis.

Since the target-mask prevented parafoveal processing of the target word, this means that the pre-target predictability effect obtained here cannot be the result of either mis-located fixations or a genuine parafoveal-on-foveal influence. Additionally, the pre-target effect does not appear to reflect processing difficulty associated with the pre-target word either or an effect would also have been apparent in the measure of go-past. Furthermore, the effect is unlikely to have been the result of cued memory retrieval in which there is no parafoveal processing of the target word since this hypothesis predicts an effect in the opposite direction. It is also unlikely that the effect reflects a process of pure word-anticipation which does not involve memory retrieval at all. Such a process would likely assume that during fixation of a pre-target word, the number of lexical candidates (predictions) generated at this point should decrease as contextual constraint increases (since in high-constraining sentences it will be fairly apparent what the up-coming word will be). Thus, if this hypothesis is true, and if there is no cued memory retrieval, then this might predict decreasing fixation durations on the pre-target word as target-predictability increases. However, this is unlikely to be the cause of the effect here since the same effect was not obtained in the unmasked condition. That is, there is no reason to assume that such a process of word-anticipation would be affected by either the presence or the absence of the target-mask.

Given that the cause of the pre-target predictability effect does not appear to be linked to the contextual constraint of the sentence leading up to the target word, and since it could definitely not have been related to lexical access of the parafoveal word, it appears instead to be related to the fact that parafoveal processing of the target word was prevented in the masked condition. Thus, overall, the most parsimonious explanation for the pre-target effect obtained here is that when the up-coming target word was masked, more time was spent making intra-word regressions. The fact that fixation durations decreased as up-coming predictability increased, is likely to be an artefact of the target-preview-mask. Indeed, the absence of parafoveal preview information is atypical of normal text, meaning that it is possible that the masking manipulation employed here did not provide the best possible tool for discriminating between the two versions of the cued memory retrieval hypothesis. It should also be recalled that there was a hint of an inverted effect of predictability in the unmasked condition, and that there was an interaction between sentence context and preview type on the pre-target word, thus implying that different processes were operating depending on whether the preview of the target word was available or not. These outcomes might therefore suggest that although the present study failed to replicate the inverted pre-target predictability effect shown in previous studies (e.g. Kliegl, et al., 2006; Kennedy, et al., submitted; Chapter 6, this thesis), it is possible that when the critical word is available for parafoveal processing, any pre-target effects of predictability obtained could be ones relating to a process of cued memory retrieval in which parafoveal processing plays a role.

Given that the nature of the pre-target predictability effect obtained in Chapter 6 is as yet unidentified, and since there was evidence to suggest that different processes were operating on the pre-target word depending upon the nature of the target-preview, it is necessary to further investigate whether a process of cued memory retrieval can account for pre-target predictability effects. One way to further address this issue would be to replicate the present experiment but replace the masked condition with a non-predictable word. If an inverted effect is obtained on the pre-target word in the non-predictable preview condition, then this would suggest that the pre-target predictability effects reported in previous studies are not due to a process of cued memory retrieval which entails parafoveal access of a critical word. This type of manipulation would also allow further investigation into the nature of very early effects of predictability. That is, if early effects of predictability are obtained, and these do not interact with target-preview-type, then this would suggest that early effects are not related to lexical access of the critical word. Of course, a potential problem with the proposed manipulation would be that the preview is no longer ‘neutral’, meaning that processing strategy on the pre-target word would be potentially susceptible to interference effects caused by other properties of the preview. However, this confound could be minimised by ensuring that the preview was correctly spelled, plausible, and occurred within the same semantic domain as the predictable word.

The data prior to the target word have not provided any evidence to suggest that word-anticipation processes operate during reading, thus it is now necessary to consider the aetiology of the predictability effects which were obtained on the target word. It should be recalled that a word-prediction account of predictability effects predicts a graded effect of predictability, and also implies that no predictability effect should be apparent when the target-preview is unavailable for processing. That is, since the word-prediction theory proposes that readers use a combination of contextual and parafoveal information to make predictions about up-coming words, the absence of parafoveal preview information should make it impossible to generate predictions. Similarly to the previous experiment, the relationship between predictability and fixation duration was shown to be monotonic. However, it was further shown that the nature of the target-preview did not determine whether or not a predictability effect was subsequently obtained, meaning that it is unlikely that the predictability effects obtained here were due to a process of word-prediction.

The present outcome clearly differs from that reported in Chapter 5 in which the predictability effect was eradicated following a severely misspelled preview, however, it is unlikely that this latter outcome was due to an inability to make predictions about the up-coming word. Instead it is more likely that the effect disappeared due to misleading information in the misspelled preview condition. Thus, the masking manipulation employed here arguably provided a more ecologically valid test of the word-prediction hypothesis than the misspelled preview manipulation employed in Chapter 5, yet there was no good evidence for the hypothesis.

The target-predictability effects shown here could be plausibly accounted for by an interactive-activation type process of word recognition in which contextual and parafoveal information is used to drive lexical access (e.g. McClelland & O'Regan, 1981). This is because, as well as predicting a graded effect of predictability, this type of theory predicts that in the absence of parafoveal preview information, lexical access will simply be delayed until the target word is actually fixated. Therefore, according to this viewpoint, which is of course also inherent in both the *E-Z Reader* and SWIFT models, and in contrast to the word-prediction hypothesis, the availability of parafoveal preview information would not be critical for obtaining a subsequent predictability effect. It should be recalled that for reasons set out in the *Introduction*, the SWIFT model actually predicts that the predictability effect should be larger when no preview information is available, yet there was no evidence for this either, meaning that the present outcome is therefore more in-line with the predictions of the *E-Z Reader* model.

Of course, it could instead be the case that, and in line with a modular theory of language processing, the predictability effect is an effect of semantic integration which is exerted at some post-lexical stage (e.g. Forster, 1979), since this might also predict a graded effect of predictability. More specifically, it could be the case that the effects are those of semantic integration arising from whether the context is constrained towards a particular semantic domain or not. Thus, when the context is heavily constrained towards a particular semantic domain, the critical word will be integrated faster as long as it is within this semantic domain. This would suggest that it is actually the meaning of the critical word which is important rather than whether the critical word is actually the predictable word or not. Such semantic integration accounts of predictability effects could therefore also explain why the present effects were unaffected by the absence of initial preview information. That is, since parafoveal processing is generally thought to be the first stage of lexical access, then it is unlikely that the nature of the target-preview should influence post-access processes.

Since it looks likely that the target-predictability effect is either the result of a facilitation of lexical access of the critical word, or is a semantic integration effect which occurs at some post-lexical stage, it is necessary to try to distinguish between these two accounts. As discussed above, if the predictability effect is one relating to the semantic integration of a word into the overall meaning of the sentence, then it should not actually be dependent upon the predictability of the critical word per se. Thus, the semantic integration theory can be tested by replacing the target words employed in the present study with plausible words which are non-predictable but which are within the same semantic domain as the original target words. If any target-word effects are obtained which are similar in form to those reported here and in Chapter 6, then they cannot be attributed to the predictability of the target word per se. This outcome would therefore suggest that the effects are those of semantic integration as opposed to being ones relating to a facilitation of lexical access of the critical word.

In sum, the present study has provided no evidence to suggest that predictability effects either on the critical word, or prior to the critical word, are related to word-anticipation processes. As previously discussed, the two versions of the cued memory retrieval hypothesis can be further compared experimentally by replacing the masked preview condition with a non-predictable word which is both plausible and semantically related to the original target word. Additionally, whether the target-predictability effect is one relating to lexical access of the target word, or whether it is a post-access effect of semantic integration, can be investigated by replacing the original target word with a non-predictable but plausible and semantically related word. These issues are addressed in the next chapter.

Chapter 8:

Does predictability facilitate lexical access?

8.1. Introduction

The primary aim of this chapter is to determine the extent to which the effects of predictability observed thus far can be interpreted as effects of the nature of the sentence context on the process of lexical access. This investigation is necessary given that some predictability effects were apparent at a point in the sentence that was an implausibly long distance away from the critical word, implying that those effects cannot be related to lexical access of the critical word. This therefore begs the question as to whether effects found in the region of the critical word necessarily relate to lexical access. That is, effects found on the pre-target word may or may not be parafoveal effects of lexical access while it also unclear as to whether effects on the critical word are those relating to facilitation of lexical access.

Thus far it has been shown that the target-predictability effect is not dependent upon the availability of initial preview information and that the function relating predictability and fixation durations is monotonic. As previously discussed in Chapters 6 and 7, an interactive-activation type process of word recognition in which contextual and parafoveal information is used to drive lexical access could account for these findings. It should be recalled that according to McClelland & O'Regan's (1981) model, for example, contextual information along with parafoveal information can be combined to provide sufficient activation for a logogen to surpass its threshold. When the context is less constrained towards a particular word, many logogens will be activated and it will take longer for the correct logogen to surpass its threshold. Thus, this type of theory could account for the graded effects of predictability shown. Additionally, this type of process does not necessarily imply that the predictability effect depends critically upon the availability of initial parafoveal information, since it predicts that in the absence of parafoveal preview information, the process of lexical access will simply be delayed until the word is eventually fixated. Thus, an interactive-activation type process could also account for the fact that the predictability effect does not appear to be modulated by the presence or absence of the target-preview.

Although chapters 6 and 7 provide evidence consistent with the idea that predictability effects may be the result of a contextual facilitation of lexical access of the critical word, chapters 4 and 5 provide evidence which may suggest the contrary. That is, when taken together, the outcome of the first two experiments provide evidence to suggest that word-frequency and word-predictability exert additive effects in fixation durations. If Sternberg's (1969) Additive Factors logic can be plausibly applied to fixation durations, then such effects would either suggest that the variables affect different processes or that they both affect the same process but do not interact. It should be recalled that the *E-Z Reader* model predicts the latter. That is, while frequency and predictability are combined additively in the model, the variables also both influence an initial stage (L_1) as well as a later stage (L_2) of word-encoding. In the SWIFT model, frequency and predictability are not combined in a single equation for word-difficulty, meaning that this model neither predicts additive nor interactive effects, although similarly to *E-Z Reader*, SWIFT predicts that the variables influence the same stage of word-encoding. However, it is possible that the reason that the variables exert additive effects in fixation durations is because they affect different processes. As discussed in Chapter 2, it is widely assumed that word-frequency exerts an access effect (although c.f. Balota,1990). Whaley (1978) for example, provided evidence to suggest that word-frequency is the most important factor in determining response-speed in the lexical decision task (a task which is assumed to capture lexical access time). Thus, if predictability exerts an effect at a different stage to that of frequency, then it is plausible that it could be at a later post-lexical-access stage.

If predictability exerts its influence at some post-access stage, then predictability effects may be better accounted for by models of language processing assuming an autonomous lexical processor unaffected by sentential context (e.g. Forster, 1979). According to this type of theory, context only influences post-access processes. So, it could be the case for example, that predictability effects on the critical word are effects of semantic integration of the word into the sentence frame after it has been accessed. This type of theory suggests that it is the meaning of the critical word which is of importance, as opposed to whether the critical word varies in predictability per se, implying that the predictability effect arises from whether the context is heavily constrained towards a particular semantic domain or not. Thus, a semantic integration account of predictability predicts that when the context is heavily constrained towards a particular semantic domain, the critical word will be integrated faster as long as it is within this semantic domain. When the sentence is less constrained towards a particular semantic domain, it will take longer for the meaning of the same critical word to be integrated with the meaning of the sentence, since the global meaning of the sentence will be less apparent in less-constraining sentences. If this hypothesis is true, this suggests that the critical word does not actually have to be a predictable word, it only has to be a plausible and semantically appropriate word, and would be consistent with a growing body of literature which suggests that global contextual information, such as the nature of the critical word being described in the sentence, influences semantic interpretation on a critical word (e.g. Cook & Myers, 2004; Filik, 2008; Garrod & Terras, 2000; Hagoort, Hald, Bastiaansen & Petersson, 2004). As well as being able to account for the monotonic relationship between predictability and fixation durations shown thus far, the idea that predictability effects are in fact post-lexical semantic integration effects can also explain why the predictability effect does not appear to be modulated by the presence or absence of parafoveal preview information. This is because, parafoveal processing is generally associated with the initial stages of word-encoding as opposed to post-lexical processes.

Since the predictability effects obtained thus far can be accounted for by either a process of semantic integration which occurs at some post-access stage, or by an interactive-activation type process in which contextual and parafoveal information are used to drive lexical access, it is now necessary to distinguish between these two possible accounts. This is important not only for determining the nature of predictability effects, but for distinguishing between theories of language processing. If the semantic integration account of predictability effects were shown to be true for example, then this would provide evidence for a modular theory of language processing, whilst providing evidence against an interactive theory. Additionally, it would suggest that the way in which predictability is modelled in both the *E-Z Reader* and the SWIFT models is incorrect, since in both models, predictability effects are assumed to be effects on lexical access.

When parafoveal processing of the critical word is prevented, it is not possible that the pre-target predictability effect, such as that obtained in the previous study, can be a parafoveal effect of lexical access. Thus, the effect obtained in the masked condition in the previous experiment provided some evidence against the perceptually-cued version of Kliegl, Nuthmann and Engbert's (2006) cued memory retrieval hypothesis. However, it was also shown that this effect was not related to a process of pure word-anticipation (in which there is no role played by parafoveal perceptual input), since the same effect was not obtained in the unmasked condition. Instead, the effect was more likely to have been a consequence of the pixel masking manipulation employed. This means that the masked condition perhaps did not provide the best possible test of the perceptual input version of the cued memory retrieval hypothesis. Additionally, since in the previous experiment, an interaction between sentence context and preview type was obtained on the pre-target word, with a hint of an inverted effect in the unmasked condition, this implied that different processes were operating depending on whether the preview of the target word was available or not. This means that it is still possible that when the critical word is available for parafoveal processing, any pre-target effects of predictability obtained (e.g. Kliegl, et al., 2006; Kennedy, Pynte, Murray & Paul, submitted; Chapter 6, this thesis) could be ones of lexical access. Thus, while there is evidence to suggest that some pre-target effects are definitely not ones of lexical access, there is some evidence to suggest that others may be. It is crucial to determine whether pre-target effects of predictability, as well as very early effects of predictability, are ever related to lexical access of the critical word in order to determine the nature of early predictability effects.

In order to determine whether the pre-target parafoveal effects are ones related to the predictability of a particular lexical item, in the present experiment the same sentence frames employed in the previous experiment are used, but the word available in the parafovea is manipulated so that it is either the predictable word or a non-predictable word which is nonetheless, a plausible continuation of the sentence. If an effect of sentence context is obtained on the pre-target word when the non-predictable word is present in parafoveal vision, and there is no interaction between sentence context and the type of target-preview initially available, then this would suggest that pre-target effects are not parafoveal access effects. Moreover, if an inverted effect of context is obtained when the non-predictable word is available, and is therefore similar to that obtained in the studies by Kliegl et al. (2006; Kennedy et al., submitted; Chapter 6, this thesis), then this would provide good evidence to suggest that the effects in those studies were not parafoveal access effects, and will provide evidence against the perceptual input version of the cued memory retrieval hypothesis. However, if an effect of sentence context is obtained on the pre-target word when the predictable word is present in parafoveal vision, and if this effect is inverted in form, then this would provide evidence for a process of cued memory retrieval involving parafoveal processing of the predictable word.

In order to ascertain whether critical word effects are ones to do with lexical access, the target word in the present experiment is always a non-predictable word. This means that if an effect of context is obtained on the critical word, then predictability effects must be semantic integration effects rather than ones relating to facilitation of lexical access. Of course, in half of the cases, the critical word will change from being a predictable word while in parafoveal vision, to being a non-predictable word upon fixation and it is likely that this ‘mis-match’ will cause some inhibition effects on the critical word due to activation of the ‘incorrect’ preview. Whether an interaction is obtained between preview and contextual constraint will also help shed some light on the nature of the predictability effect. If context facilitates lexical access of a word, then a specific word or sub-set of words must initially be activated in more constraining sentences so that facilitation can then occur, while in less constraining sentences, it is less likely that a specific word or sub-set is activated. If this theory is true, then when the sentence is heavily constrained towards the predictable target-preview, the inhibition on the critical word following the mis-match should be greater than when the sentence is less constrained, due to the critical word not being the word that was activated or initially processed parafoveally. Thus, a greater preview benefit on the critical word for more constraining sentences would provide some evidence for predictability effects being ones of lexical access, and would be consistent with both the SWIFT and *E-Z Reader* models as well as an interactive theory of language processing, while no interaction would provide evidence to suggest that context effects on the critical word are effects of semantic integration.

8.2. Method

8.2.1. Participants

Forty undergraduate students from the University of Dundee participated in the experiment. All were native English speakers with normal or corrected-normal vision and had no known language difficulties. Participants received £5 for participating.

8.2.2. Materials and Design

The 48 sentence frames from Experiment 4 were employed in the present experiment. It will be recalled that the experimental items were designed so that the sentences were either more or less contextually constrained towards one specific target word. However, in the present experiment, the predictable and unpredictable target words were replaced with non-predictable but plausible words (see Appendix K for full list of items and Figure 8.1. for example item). This resulted in four conditions which varied in terms of 'contextual constraint'.

1*a*. Liz was cutting the hedges and watering the plants in the pretty *garden/estate* <u>estate</u> behind her house.

1*b*. Catriona's friend could be seen watering the plants in the pretty *garden/estate* <u>estate</u> behind her house.

1*c*. The elderly lady could be seen bird-watching in the pretty *garden/estate* <u>estate</u> behind her house.

1*d*. Catriona painted an absolutely wonderful picture of the pretty *garden/estate* <u>estate</u> behind her house.

Figure 8.1. An example item showing each of the four contextual constraint conditions. The sentence frames were either more or less constrained towards a particular target word, although the target word (underlined) was non-predictable. The parafoveal previews (italicized) of the target words could be either predictable or non-predictable. Examples a, b, c and d are the High-Constraint, Moderate-Constraint, Low-Constraint and Non-Constraint contextual constraint conditions respectively.

To ensure that the target words were non-predictable, words were chosen that were never given as a response in the cloze task carried out for Experiments 3 and 4. As shown in Table 8.1, these words were of the exact same length and of similar word-frequency to the target words employed in the latter two experiments.

Table 8.1. Mean (and range of) word lengths (in characters) and word frequencies for target words employed in Experiments 3, 4 and 5.

Experiment	Target length (mean)	Target length (range)	Target freq (mean)	Target freq (range)
Three	5.7	5 - 7	32	1 - 127
Four	5.8	5 - 7	35	1 - 127
Five	5.8	5 - 7	36	1 - 377

In order to ensure that the target words were plausible within the context of the sentence frames, an independent group of 12 participants was asked to rate the plausibility of the experimental sentences. The instructions for the task were the same as those for the plausibility task used in Experiments 3 and 4 (see Appendix C). The participants were asked to rate the plausibility of all 192 of the experimental sentences and 108 filler sentences (54 of which were plausible and 54 were implausible). Participants received course-credit for completing the plausibility rating task which took approximately 40 minutes.

The mean plausibility ratings for the experimental items used in all three experiments are shown in Table 8.2 below. The results of a repeated measures ANOVA revealed that there was no significant variation in Plausibility across experimental conditions, $F(3, 141) = 1.41$, $p = 0.24$, implying that any target-word effects obtained in the present study are unlikely to be due to variations in measured sentential plausibility. In addition, the results of a mixed ANOVA revealed that there was no significant variation in Plausibility across the Experiments, $F(2, 125) = 0.06$, $p = 0.94$, and no Plausibility by Experiment interaction, F (6, 375) = 0.19, p = 0.98, indicating that the patterns of sentence plausibility did not differ significantly between experiments.

Table 8.2. The mean (and range of) plausibility ratings for each of the four types of sentence frames for Experiments 3, 4 and 5.

Contextual constraint of sentence fragment preceding target word	Experiment	Mean plausibility of sentence frame (out of 7)	Range
High-Predictable	Three	6.0	3.2 – 6.8
	Four	5.9	3.2 – 6.8
	Five	5.7	3.0 – 7.0
Moderate-Predictable	Three	5.8	3.2 – 6.4
	Four	5.8	3.2 – 6.6
	Five	5.7	2.9 – 6.6
Moderate-Unpredictable	Three	5.8	3.1 – 6.8
	Four	5.8	3.1 – 6.8
	Five	5.6	2.9 – 6.9
Unpredictable	Three	5.7	3.1 – 6.7
	Four	5.6	2.9 – 6.7
	Five	5.5	3.0 – 6.2

Similarly to the previous experiment, 8 lists were constructed from the 48 experimental base items (giving 392 items in total). Eight lists were employed because the first factor ‘Contextual Constraint’ had four levels and the second factor ‘Preview’ had two levels, resulting in eight versions of each item. That is, each item was either Highly-Constrained, Moderately-Constrained, Low-Constrained or Non-Constrained towards the target word (although the target word was in fact always non-predictable) giving four versions of each base item. In the base items, the preview of the target word was always the same as the target word, thus producing a ‘No Change’ condition. A further four versions of each base item were employed in which the preview of the target word was either more or less predictable depending upon the preceding sentence context (the previews were the target words employed in the previous experiment). Via the contingent boundary procedure, these previews changed to the non-predictable target word upon fixation, thus producing a ‘Change’ condition. The 40 participants were randomly assigned to one of the 8 counterbalanced item lists with 5 participants allocated to each. Each list included 48 items (6 from each of the 4 ‘No change’ contextual constraint conditions and 6 from each of the 4 ‘Change’ contextual constraint conditions). Items were rotated using a counterbalanced design such that no base item occurred in more than one contextual constraint or preview condition within a single list.

The experimental items were mixed in with the same 48 filler sentences and 8 practice sentences used in Experiment 4. 32 comprehension questions were also employed, these were paired with some of the filler sentences and some of the experimental sentences.

8.2.3. Apparatus

Eye movements were recorded using the same Dr. Bouis pupil-centre computation Oculomotor employed in the previous experiments. The general procedure was identical to that used in the preceding experiments which involved an eye-movement contingent change (Experiments 1, 2 and 4), with the display change triggered as soon as the eyes crossed an invisible boundary located after the last letter of the pre-target word.

8.2.4. Procedure

The procedure was the same as Experiment 4. On arrival, participants were given oral instructions as described in the previous chapter. They were then given a set of written instructions (see Appendix H) which were also the same as those given in Experiment 4.

8.3. Results and Discussion

In the same way as the previous experiment, the experimental sentences were divided into six zones and the four critical zones were analysed using 2 x 4 mixed ANOVA's.

Participants read the sentences carefully with overall accuracy on the comprehension questions of 98%.

8.3.1. Analysis of zone 2 - the region prior to the pre-target word

Table 8. 3. Mean First-Fixation duration, Go-Past duration, Gaze duration, Re-reading time and Total Reading time (in ms) derived from zone 2.

Measure	No Change				Change			
	H-C	M-C	L-C	N-C	H-C	M-C	L-C	N-C
First Fix	248	264	253	253	255	254	260	258
Gaze	458	464	484	460	430	494	474	436
Go-past	544	547	556	502	504	555	580	491
Re-read	86	83	72	43	74	60	106	54
TRT	535	550	568	537	526	590	568	537

Note: H-C = High-Constraint, M-C = Moderate-Constraint, L-P = Low-Constraint, N-C = Non-Constraint. TRT = Total Reading time.

It can be seen from Table 8.3 that first fixation durations in zone 2 were not significantly influenced by the Contextual Constraint of the sentence leading up to the target word, or by the nature of the target-word Preview, all F's < 1. There was also no Contextual Constraint by Preview interaction in this measure, F's <1.

There were hints of an effect of Contextual Constraint in go-past, F_1 (3,96) = 4.88, p < 0.01; F_2 (3,120) = 1.86, p = 0.14, gaze duration, F_1 (3,96) = 4.65, p < 0.01; F_2 (3,120) = 1.17, p = 0.32, and total reading time, F_1 (3,96) = 5.81, p < 0.01; F_2 (3,120) = 1.54, p = 0.21, with longer inspection times when the context of the sentence was Moderately-Constrained or Low-Constrained towards a particular word, although the effect was clearly not very consistent across items. This pattern differs from that obtained in Experiment 3 in which inspection times were longer for High- and Moderate-Predictable items, meaning that unlike Experiment 3, the present effects are not compatible with a process of word-anticipation in which readers generate predictions about an up-coming word when the sentence context is heavily constrained towards a particular word. It should be recalled that such a process predicts that fixation durations should be inflated in more constraining sentences. The present data also differs from Experiment 4 in which longer inspection times were obtained for Moderate-Predictable and Unpredictable items. Thus, the precise nature of early context effects is still not immediately apparent given that the sentence frames up to the target word were the same across all three experiments. It is unlikely that this difference in pattern is due to the nature of the target word itself, given that there were no significant effects here of Preview in either the go-past duration, gaze duration, re-reading time or total reading time results, all F's <1.

To ascertain whether the context effects obtained in zone 2 are related to lexical access of the target word, it is necessary to investigate whether a Contextual Constraint by Preview interaction is apparent. It will be recalled that in half of the cases, the preview varied in predictability (and an effect in this condition only would suggest lexical access effects) while in the other half of the cases, the preview was non-predictable. The Contextual Constraint by Preview interaction was not significant in either go-past duration, F_1 (3,96) = 1.24, p = 0.30; F_2 (3,120) = 0.71, p = 0.55, gaze duration, F_1 (3,96) = 1.75, p = 0.16; F_2 (3,120) = 1.14, p = 0.34, total reading time, F_1 (3,96) = 1.64, p = 0.18; F_2 (3,120) = 0.75, p = 0.53, or re-reading time, F's < 1. It seems that the (albeit non-significant) contextual constraint effects in the present study were not influenced by the nature of the target-Preview and therefore the difference in pattern between experiments 3 – 5 is not due to the nature of the target words employed in the experiments. The possible aetiology of the zone 2 effects will be discussed in section *8.4*.

8.3.2. Analysis of zone 3 - the pre-target word

Table 8. 4. A range of Reading Time measures (in ms) derived from zone 3, together with probability of Skipping zone 3 (in characters).

Measure	No Change				Change			
	H-C	M-C	L-C	N-C	H-C	M-C	L-C	N-C
Skip	0.18	0.14	0.15	0.16	0.14	0.19	0.17	0.16
First Fix	264	261	265	256	257	261	263	271
Gaze	229	237	237	230	237	230	232	243
Go-past	249	270	269	248	254	261	253	273
Re-read	20	32	32	18	17	31	22	30
TRT	269	306	296	288	285	282	284	291

Note: H-C = High-Constraint, M-C = Moderate-Constraint, L-P = Low-Constraint, N-C = Non-Constraint. TRT = Total Reading time.

As can be seen from Table 8.4, neither the Contextual Constraint of the sentence, nor the nature of the target-Preview significantly influenced any of the measures derived from zone 3, all F's < 1. There were also no significant Contextual Constraint by Preview interactions in any of the measures, all F's < 1.

The fact that no 'parafoveal predictability' effect was found here with the non-predictable previews provides evidence against a process of cued memory retrieval in which there is no parafoveal processing of a predictable word. Additionally, the lack of effect with predictable previews does not support a process of cued memory retrieval entailing parafoveal perceptual input from the predictable word. It will be recalled that the apparent inverse effect of predictability found in Experiment 3 was not replicated in Experiment 4. To that we can add the fact that here in the 'predictable item preview condition' there was no sign of an effect. Therefore there seems to be little evidence to support the suggestion that pre-target effects of predictability are parafoveal access effects. However, given that this issue is theoretically important, it was worthwhile further examining the zone 3 data using *lmer* which provides the opportunity to analyse the Contextual Constraint and Preview factors as continuous variables. These analyses are reported in section *8.3.6.*

8.3.3. Analysis of zone 4-the target word

Table 8. 5. A range of Reading Time measures (in ms) derived from zone 4, together with probability of Skipping zone 4 (in characters).

Measure	No Change				Change			
	H-C	**M-C**	**L-C**	**N-C**	**H-C**	**M-C**	**L-C**	**N-C**
Skip	0.12	0.16	0.13	0.13	0.13	0.10	0.18	0.11
First Fix	260	249	261	266	271	269	280	275
Go-past	265	270	292	313	293	327	299	330
Gaze	242	231	252	257	262	278	246	279
Re-read	23	39	40	55	31	49	53	51
TRT	310	321	339	369	314	338	299	358

Note: H-C = High-Constraint, M-C = Moderate-Constraint, L-P = Low-Constraint, N-C = Non-Constraint. TRT = Total Reading time.

It can be seen from Table 8.5 that there were no main effects of Preview, F's < 1, nor Contextual Constraint, F_1 (3,96) = 1.55, p = 0.21; F_2 (3,120) = 1.09, p = 0.35, on the rate that the target word was skipped. However, there was a trend towards a Contextual Constraint by Preview interaction, F_1 (3,96) = 1.84, p = 0.14; F_2 (3,120) = 2.60, p = 0.05, see Figure 8.2. Further analyses revealed that the main effect of Contextual Constraint was not significant in the No Change condition, F's < 1, but was significant in the Change condition, F_1 (3,117) = 3.24, $p < 0.05$; F_2 (3,141) = 3.12, $p < 0.05$. Pair-wise comparisons indicated that the target word was more likely to be skipped when the target-preview was Low-Predictable than when it was Moderate-Predictable ($p_1 < 0.01$; p_2 = 0.11). This effect is clearly not what is typically reported in the literature and is not easily interpretable. What can be ascertained, however, is that skipping effects associated with word-predictability, seem to be related to the nature of the word in parafoveal vision and not just the contextual nature of the sentence preceding the word. This outcome is of course potentially consistent with both the *E-Z Reader* and the SWIFT models which suggest that skipping occurs because the word has been processed parafoveally.

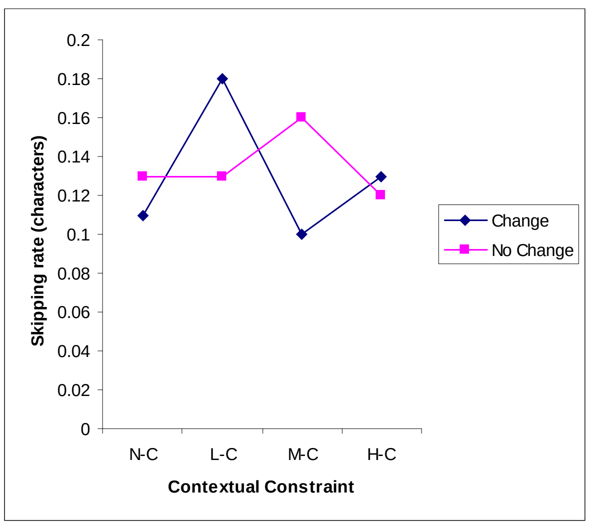


Figure 8.2. Skipping rate in zone 4.

The nature of the target-Preview significantly influenced first fixation durations, F_1 (1,32) = 10.76, $p < 0.01$; F_2 (1,40) = 8.47, $p < 0.01$, go-past durations, F_1 (1,32) = 5.35, $p < 0.05$; F_2 (1,40) = 4.11, $p < 0.05$, and gaze durations, F_1 (1,32) = 8.59, $p < 0.01$; F_2 (1,40) = 4.40, $p < 0.05$, on the target word, see Figures 8.3, 8.4 and 8.5 respectively. As predicted, inspection times were longer when the target-Preview changed upon fixation than when it did not change, indicating that the ‘mis-match’ caused a disruptive effect.

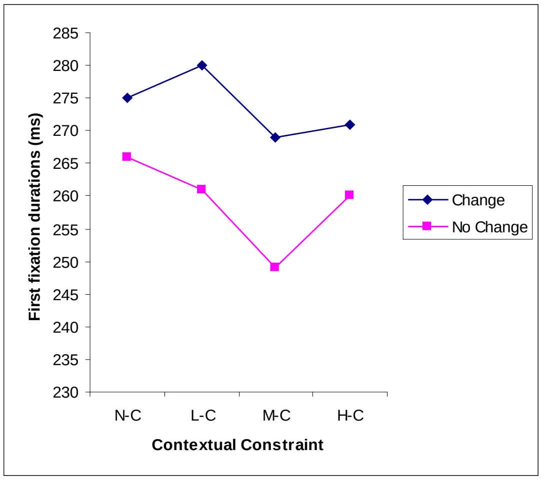


Figure 8.3. First fixation durations in zone 4.

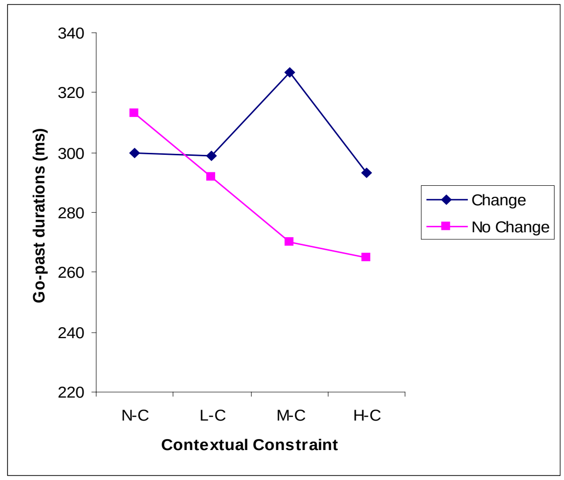


Figure 8.4. Go-past durations in zone 4.

The Contextual Constraint by Preview interaction was not significant in either first fixation durations, F’s < 1, or go-past durations, F_1 (3,96) = 1.04, p = 0.38; F_2 (3,120) = 1.39, p = 0.25. Thus, there was no evidence that processing strategy on the target word differed depending upon the nature of the prior preview. However, there was a trend towards an overall effect of Contextual Constraint in first fixation durations, F_1 (3,96) = 2.34, p = 0.08; F_2 (3,120) = 2.04, p = 0.11. Inspection times on the critical word were generally longer when the preceding context was less-constrained towards a particular word, see Figure 8.3. This effect of Context Constraint became significant in go-past, F_1 (3,96) = 2.94, $p < 0.05$; F_2 (3,120) = 2.81, $p < 0.05$, with significantly shorter inspection times on the critical word when the preceding context was Highly-Constrained towards a particular word than when it was Non-Constrained (p_1 & $p_2 < 0.05$).

The fact that the above Context effects were not dependent upon the nature of the prior preview implies that they arose solely as a result of the nature of the preceding sentence context rather than being an effect of the predictability of the target word per se. That is, it suggests that the effects are not related to a contextual facilitation of the lexical access of the target word, but instead may be due to the integration of the critical word into the meaning of the preceding sentence frame.

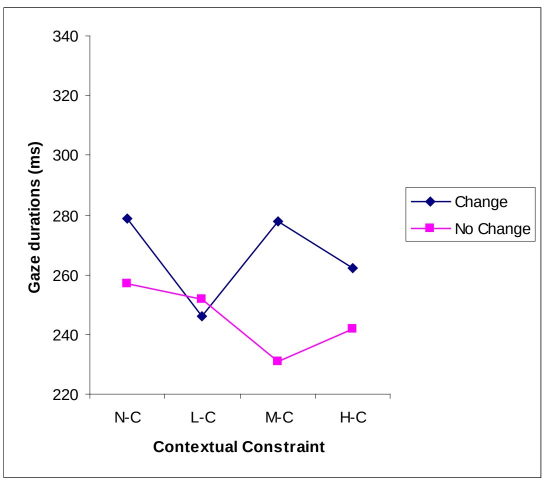


Figure 8.5. Gaze durations in zone 4.

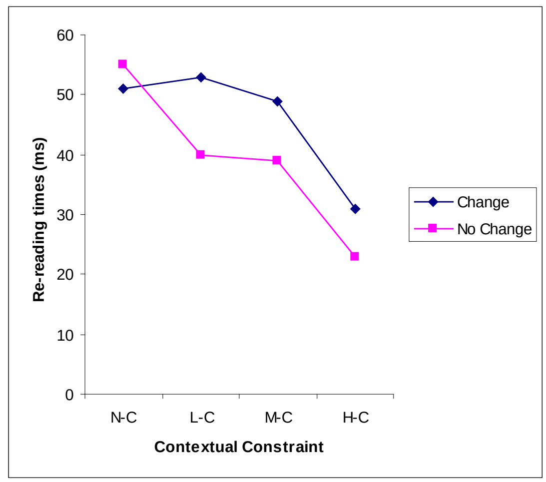


Figure 8.6. Re-reading times in zone 4.

Unlike the first fixation duration and go-past duration data, there was no overall effect of Contextual Constraint in either gaze, F_1 (3,96) = 1.54, p = 0.21; F_2 (3,120) = 2.11, p = 0.10, or re-reading time, F_1 (3,96) = 1.82, p = 0.15; F_2 (3,120) = 1.71, p = 0.17. The latter outcome implies that the effect of Contextual Constraint obtained in go-past was not driven by the time spent re-reading. Also unlike the previous inspection time measures, the Contextual Constraint by Preview interaction was close to becoming significant in gaze, F_1 (3,96) = 2.33, p = 0.08; F_2 (3,120) = 2.28, $p < 0.05$, see Figure 8.5. The overall form of the interaction provides some evidence to suggest that when the Preview did not match the target word, there was more disruption in the conditions in which the sentences were more contextually constrained towards a particular word. However, further analyses revealed that the effect of Contextual Constraint was in fact not significant in both the Change, F_1 (3,96) = 2.21, $p = 0.09$; F_2 (3,120) = 2.58, $p = 0.06$, and No Change, F_1 (3,96) = 1.62, $p = 0.19$; F_2 (3,120) = 2.43, $p = 0.07$, conditions. Additionally, there was no Contextual Constraint by Preview interaction in re-reading time, F's < 1. Thus, overall, the measures of inspection time taken do not provide any concrete evidence to suggest that processing strategy on the target word was dependent upon the nature of the prior preview.

Unlike the previous inspection time data, the effect of Preview was non-significant in both the re-reading time and total reading time data, all F's < 1. These outcomes are logical however, given that the preview was available for processing before the target word was even fixated. That is, any effects of Preview on the target word should be apparent earlier in the eye-movement record rather than later, and this is what has been shown. The total reading time data also revealed a significant effect of Contextual Constraint, F_1 (3,96) = 5.67, $p < 0.01$; F_2 (3,120) = 5.91, $p < 0.01$. Figure 8.7 shows that overall reading times were shorter when the items were Highly-Constrained towards a particular word than when they were Non-Constrained (p_1 & $p_2 < 0.01$). They were also shorter when they were Less-Constrained towards a particular word than when they were Non-Constrained ($p_1 < 0.01$; $p_2 < 0.05$). This effect was not dependent upon the nature of the prior preview, F's < 1.

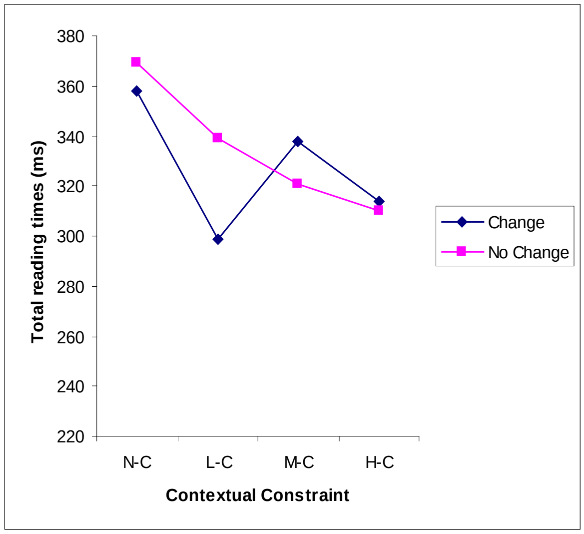
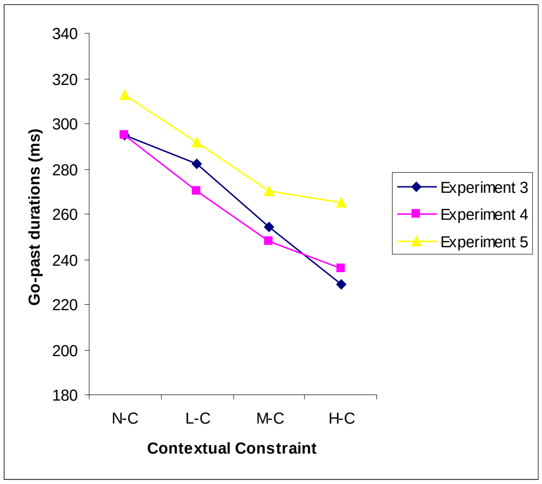


Figure 8.7. Total reading times in zone 4.

On balance, the data thus far suggest that the sentence context effects obtained on the critical word are not related to lexical access of this word. The only caveat being that there was a hint of a Contextual Constraint by Preview interaction in gaze. Since whether or not an interaction is obtained, bears on the central issue addressed by this experiment, it was relevant to further investigate whether this interaction was significant in gaze by carrying out *lmer* analyses in which the Contextual Constraint factor was defined as a continuous variable. These analyses are reported in section *8.3.7*.

It was also highly relevant to compare the pattern of effects obtained on the critical word in this experiment with those obtained in the previous two experiments. While the critical word varied in predictability in Experiments 3 and 4, it did not in the present experiment, thus if the pattern of effects is similar across experiments, this will provide evidence to suggest that the effects are not likely to be access effects. These comparisons were made using the zone 4 data from the No Change condition employed in this experiment, the zone 4 data from the Unmasked condition in the previous experiment, and the zone 4 data from Experiment 3. That is, the comparisons employed data in which the target-preview and preview always matched. Mixed ANOVA's in which Contextual Constraint was the within factor and Experiment was the between factor, were carried out for go-past and gaze durations since the effects appear to better captured by cumulative measures such as these.



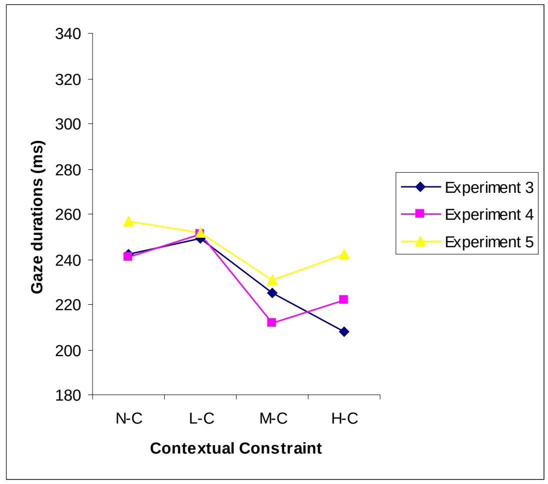


Figure 8.8. Go-past durations in Experiments 3-5. **Figure 8.9. Gaze durations in Experiments 3-5.**

The results of the ANOVA's revealed that there was a significant effect of Context across all three experiments in both go-past, F_1 (3,327) = 10.15, p < 0.001; F_2 (3,375) = 9.43, p < 0.001, and gaze, F_1 (3,327) = 9.17, p < 0.001; F_2 (3,375) = 9.12, p < 0.001, see Figures 8.8 and 8.9 respectively. Critically, these effects did not differ between experiments, as there was no significant effect of Experiment in either go-past, F_1 (2,109) = 0.98, p = 0.38; F_2 (2,125) = 2.44, p = 0.09, or gaze, F_1 (2,109) = 1.15, p = 0.32; F_2 (2,125) = 2.58, p = 0.08, and no significant Contextual Constraint by Experiment interaction in either go-past, F_1 (6,327) = 0.17, p = 0.98; F_2 (6,375) = 0.16, p = 0.99, or gaze, F_1 (6,327) = 0.88, p = 0.51; F_2 (6,375) = 0.71, p = 0.64.

Overall, these analyses suggest that the context effects obtained on the critical word in Experiments 3, 4 and 5, are not due to the facilitation of lexical access by a predictive context. Indeed, this clearly could not be the case in Experiment 5 where the target word did not vary in predictability.

8.3.4. Analysis of zone 5-the region following the target word

As can be seen from Table 8.6, the measure of first fixation duration showed no effect of Preview or Contextual Constraint, all F's < 1, and no significant interaction between Preview and Contextual Constraint, F_1 (3,96) = 1.23, p = 0.30; F_2 (3,120) = 0.75, p = 0.53.

Table 8. 6. A range of Reading Time measures (in ms) derived from zone 5.

Measure	**No Change**				**Change**			
	H-C	**M-C**	**L-C**	**N-C**	**H-C**	**M-C**	**L-C**	**N-C**
First Fix	260	265	258	251	254	260	268	259
Go-past	393	429	401	373	351	329	390	369
Gaze	304	329	303	281	292	288	332	295
Re-read	89	100	98	92	60	41	57	74
TRT	429	436	424	412	386	394	428	400

Note: H-C = High-Constraint, M-C = Moderate-Constraint, L-P = Low-Constraint, N-C = Non-Constraint. TRT = Total Reading time.

The nature of the target-Preview did however, influence go-past durations in zone 5, F_1 (1,32) = 6.20, p < 0.05; F_2 (1,40) = 9.75, p < 0.01, with shorter inspection times in the Change condition than in the No Change condition, see Figure 8.10. The direction of this effect is the inverse of the effect obtained in go-past durations for zone 4 (Figure 8.3), and suggests that a trade-off occurred: When the target word did not match the preview, more time was spent processing the target word itself. A consequence of this was less time spent looking back towards the target word when the eyes were in zone 5. This inference is supported by the fact that while the effect of target-Preview was not significant in gaze, F's < 1, a measure which does not capture the time spent making inter-word regressions, it was significant in re-reading times, F_1 (1,32) = 11.26, $p < 0.01$; F_2 (1,40) = 10.88, $p < 0.01$, see Figure 8.11.

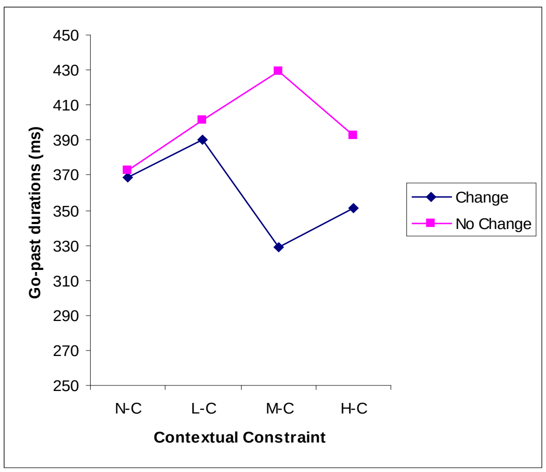


Figure 8.10. Go-past durations in zone 5.

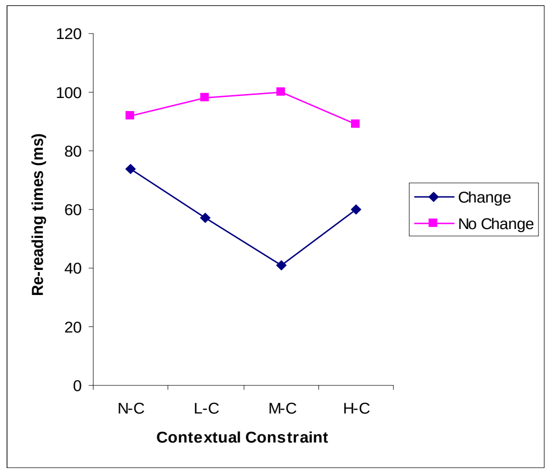


Figure 8.11. Re-reading times in zone 5.

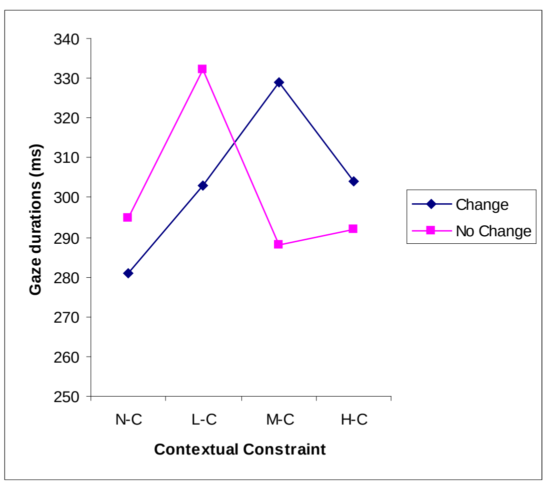


Figure 8.12. Gaze durations in zone 5.

There was a trend towards an effect of Contextual Constraint in gaze, F_1 (3,96) = 2.89, $p < 0.05$; F_2 (3,120) = 1.74, $p = 0.07$, see Figure 8.12. Gaze durations generally increased as the contextual constraint of the preceding sentence decreased, although this was not the case for when the sentence was Non-Constrained towards a particular word. This trend was not driven by the time spent looking back towards the target word since the effect was not significant in either go-past durations or re-reading times, F's < 1.

The Contextual Constraint by Preview interaction was close to significant in go-past durations, F_1 (3,96) = 2.78, $p < 0.05$; F_2 (3,120) = 2.33, $p = 0.08$, see Figure 8.10 above. However, further analysis revealed that the effect of Contextual Constraint was not significant in either the Change, F_1 (396) = 2.50, $p = 0.06$; F_2 (3,120) = 1.60, $p = 0.19$, or No Change, F_1 (3,96) = 1.01, $p = 0.39$; F_2 (3,120) = 1.03, $p = 0.38$, conditions. The interaction was also close to becoming significant in gaze, F_1 (3,96) = 4.43, $p < 0.01$; F_2 (3,120) = 2.40, $p = 0.07$, see Figure 8.12. The form of this interaction differed from that obtained in go-past but this difference was not due to the time spent regressing, since the interaction was not significant in the re-reading time data, F's < 1. Further analysis of the gaze data revealed that the effect of Contextual Constraint was not wholly significant in either the Change, F_1 (3,96) = 3.50, $p < 0.05$; F_2 (3,141) = 2.26, $p = 0.08$, or No Change, F_1 (3,96) = 3.50, $p < 0.05$; F_2 (3,120) = 1.88, $p = 0.14$, conditions. Thus, despite the near-significant interactions apparent in go-past and in gaze, there was no evidence to suggest that the (albeit non-significant) spill-over effect of Contextual Constraint obtained in gaze, was related to lexical access of the critical word.

Lastly, there was no effect of Contextual Constraint, and no Contextual Constraint by Preview interaction in the total reading time data, F's < 1, but similarly to the go-past duration and re-reading time data, total reading times were shorter in the Change condition than in the No Change condition, F_1 (1,32) = 4.31, $p < 0.05$; F_2 (1,40) = 6.15, $p < 0.05$.

8.3.5. Lmer analysis of Experiment Five

The *lmer* analyses were carried out using the same linear-mixed effects model framework and package described in the previous chapter. The zones analysed were zones 3 (the pre-target word) and 4 (the target word).

Lmer analysis of zone 3 enabled further investigation into whether any reliable effects of Contextual Constraint were apparent. The Contextual Constraint variable used in these analyses (as well as in the zone 4 analyses) differed from that employed with ANOVA and consisted of the predictability scores for all of the target words employed in the previous experiment. The logic here is that although the target words employed in the present experiment were non-predictable, the sentence frames employed in both the present and previous experiment were identical. Thus the predictability ratings for the target words in the prior experiment give an indication of the contextual constraint of the sentence frames up to the contingent boundary. That is, and for example, a sentence frame that strongly predicts one particular word will, by definition, be more constraining than one where participants produce a variety of continuations.

Given that during the fixation of the pre-target word, the preview of the target-word would either have been a non-predictable word or a word that varied in predictability, any effect of Contextual Constraint on the pre-target word would only be interpretable after first establishing whether the effect was dependent upon the nature of the target-preview. In order to investigate this interaction, in the *lmer* analyses for zone 3, a ‘Preview-Predictability’ variable is included. This variable differs from that employed in the initial analyses as it consists of the predictability ratings for the target-previews, meaning that it is a continuous variable in these analyses. The predictability ratings for the previews which varied in predictability (i.e. those in the Change condition) were established in the previous experiment, while the non-predictable previews (i.e. those in the No Change condition) were words which were never produced in the cloze task for the preceding experiment and were therefore assigned the predictability value of zero.

It was also necessary to investigate whether a main effect of Preview-Predictability was apparent given that previous research has indicated that inspection time on a currently fixated word is longer when the up-coming word is available for parafoveal processing and is predictable. *Lmer* analysis of zone 3 also provides the opportunity to investigate whether any Preview-Predictability effect on the pre-target word is modulated by whether the target word is eventually fixated or not. This is relevant since Kennedy et al. (submitted) have shown that pre-target predictability effects are only apparent when the up-coming word is subsequently fixated (Kennedy et al. suggest that if the pre-target predictability effect is due to a process of ‘non-perceptual’ cued memory retrieval, then this process may only kick in when the up-coming word has not been fully identified in the parafovea, which is likely to be the case when the word is not subsequently fixated). Whether measured sentence Plausibility exerts an effect on inspection strategy on the pre-target word is also investigated.

In the zone 4 analyses, the main effect of Contextual Constraint, and whether this is related to lexical access of the word is examined. The latter is achieved by investigating whether the effect is influenced by whether the target-Preview changed or not. The preview variable employed in these analyses is a binary variable (whether the Preview changed or not) and is the same as the Preview variable employed in the ANOVA analyses. The reason that Preview is employed rather than Preview-Predictability, is because the latter variable would at this point encompass two different effects - an effect of prior predictability and an effect of word change. Thus, investigating the effect of preview-predictability on the pre-target word is justified since there can be no effect of preview change at this point, but including this variable in the zone 4 analyses would make it difficult to interpret any effects in this region.

Whether there is a Skipping Rate (zone 3) by Contextual Constraint interaction is also examined in the zone 4 analyses. It will be recalled that in the previous experiment, the predictability effect on the target word was only apparent when the pre-target word had been fixated. Thus, it is necessary to further examine this issue. Whether measured sentence Plausibility exerted an influence on processing strategy in zone 4 is also investigated.

The dependent variables in the analyses for both zones are first fixation duration, go-past and gaze duration. Participants and Items are treated as random factors.

8.3.6. Lmer analysis of zone 3

The fixed effects, Contextual Constraint + Preview-Predictability + Contextual Constraint x Preview-Predictability + Plausibility + Preview-Predictability x Skipping Rate (zone 4) were entered into models (correlations between the set of independent variables are given in Appendix L) in which go-past and gaze durations were the dependent variables. Table 8.7 shows that neither the Contextual Constraint of the sentence fragment preceding the target word nor the predictability of the target-Preview influenced processing strategy on the pre-target word. Thus there is no evidence at all of pre-target predictability effects, an outcome which is incompatible with previous studies which have provided evidence of such effects (e.g. Kliegl et al., 2006; Kennedy et al., submitted). There was also no significant effect of Plausibility and no apparent Preview-Predictability x Skipping Rate (zone 4) interaction on the pre-target word. This latter outcome does not provide support for Kennedy et al.'s conclusion that foveal inspection time increases when the up-coming word is predictable, but only for cases when the up-coming word is subsequently fixated.

Table 8.7. Regression coefficients, standard errors and *t*-values for the Final Model (number of obs = 1842) for zone 3 with go-past and gaze (both in ms) as the dependent variables. Significance is estimated from tables of the *t* statistic assuming df = ∞ (i.e. values > 2.0 significant at p = 0.05.

Go-past duration as dependent variable				Gaze duration as dependent variable			
	Estimate	**Standard Error**	**t value**		**Estimate**	**Standard Error**	**t value**
Intercept	260.65	35.20	7.41	Intercept	238.69	26.56	8.99
Ctxt. Con.	-0.06	0.15	-0.38	Ctxt. Con.	-0.07	0.11	-0.64
Prev-P.	-0.34	0.48	-0.72	Prev-P.	-0.10	0.35	-0.29
Plausibility	-1.44	5.91	-0.24	Plausibility	-0.55	4.36	-0.13
Skipping Rate z4	82.64	15.21	5.44	Skipping Rate z4	42.11	11.34	3.71
Ctxt.Con. x Prev-P.	0.00	0.01	0.67	Ctxt.Con. x Prev-P.	0.00	0.00	0.50
Prev-P. x Skip z4	0.10	0.36	0.28	Prev-P. x Skip z4	-0.04	0.27	-0.14

Note: Ctxt. Con. = Contextual Constraint. Prev-P. = Preview-Predictability.

Although not central to the main issues addressed by this experiment, there were significant effects of Skipping Rate (zone 4) on processing strategy of the pre-target word, with shorter inspection times when the up-coming word was fixated than when it was skipped (go-past: 249 ms versus 319ms; gaze: 236ms versus 256ms). This outcome is compatible with a number of studies which have shown that inspection times on a currently fixated word are inflated when the up-coming word is skipped (e.g. Pollatsek, Rayner & Balota, 1986; Hogaboam, 1983; Drieghe, Rayner, & Pollatsek., 2005; Pynte, Kennedy & Ducrot, 2004; Rayner et al., 2004, although c.f. Drieghe, et al., 2004; Engbert et al., 2002; Radach & Heller, 2000), and is likely due to the fact that the to-be-skipped word was processed fully or almost fully while in parafoveal vision.

8.3.7. Lmer analysis of zone 4

In a base-line model in which go-past duration was the dependent variable, Contextual Constraint + Preview + Plausibility + Preview x Contextual Constraint + Contextual Constraint x Skipping Rate (zone 3) were entered as fixed effects. The Contextual Constraint by Preview interaction was non-significant ($\beta = -0.07$, S.E. = 0.32, $t = -0.22$) and was subsequently removed from the model. A second model was then arrived at in which Contextual Constraint x Skipping Rate (zone 3) + Preview + Contextual Constraint + Plausibility were the fixed effects (see Table 8.8).

Table 8.8. Regression coefficients, standard errors and *t*-values for the Second Model (number of obs = 1842) for zone 4 and for when zone 3 was fixated (number of obs = 1545) and skipped (number of obs = 297) with go-past and gaze (both in ms) as the dependent variables. Significance is estimated from tables of the *t* statistic assuming df = ∞ (i.e. values > 2.0 significant at p = 0.05)

Go-past duration as dependent variable				**Gaze duration as dependent variable**			
	Estimate	**Standard Error**	**t value**		**Estimate**	**Standard Error**	**t value**
Intercept	336.86	46.58	7.23	Intercept	228.38	29.56	7.73
Ctxt. Con.	-0.25	0.18	-1.43	Ctxt. Con.	-0.15	0.11	-1.35
Preview	34.73	10.39	3.34	Preview	17.92	6.52	2.75
Plausibility	-12.32	7.82	-1.58	Plausibility	-2.42	4.80	-0.50
Skipping Rate (z3)	231.77	26.33	8.80	Skipping Rate (z3)	85.32	16.55	5.16
Ctxt. Con. x Skip z3	-1.12	0.43	-2.58	Ctxt. Con. x Skip z3	-0.18	0.27	-0.67
Z3 fixated only:				**Z3 fixated only:**			
Intercept	291.62	45.82	6.37	Intercept	249.42	32.09	7.77
Ctxt. Con.	- 0.30	-0.16	-1.87	Ctxt. Con.	-0.13	0.11	-1.12
Preview	24.46	10.16	2.41	Preview	16.70	7.26	2.30
Plausibility	-3.47	7.74	-0.45	Plausibility	-1.30	5.28	-0.25
Z3 skip only:				**Z3 skip only:**			
Intercept	853.57	140.52	6.07	Intercept	224.58	60.21	3.73
Ctxt. Con.	-0.72	0.54	-1.34	Ctxt. Con.	-0.37	0.24	-1.58
Preview	69.98	33.61	2.08	Preview	24.03	14.84	1.62
Plausibility	-69.64	23.68	-2.94	Plausibility	-15.15	10.32	-1.47

Note: Ctxt. Con. = Contextual Constraint.

Table 8.8 shows that the effect of Contextual Constraint was not significant in either go-past or gaze, although the pattern of data were consistent with the ANOVA results: As

Contextual Constraint increased, inspection time decreased. However, the fact that the baseline model revealed no Contextual Constraint by Preview interaction provides evidence to suggest that this effect was not related to facilitation of lexical access.

There was no effect of measured Plausibility in either go-past or gaze. However, an effect of Preview was apparent in both measures and is significant and positive. That is, inspection times on the target word were longer when the target word differed from the prior preview.

Table 8.8 further shows large effects of Skipping Rate (zone 3), with significantly longer go-past and gaze durations on the target word when the pre-target word had been skipped than when it had been fixated (go-past: 430ms versus 272ms; gaze: 296ms versus 248ms). These effects are likely due to the fact that there would have been little preview benefit in cases where the pre-target word was skipped. There was also a Skipping Rate (zone 3) by Contextual Constraint interaction in go-past, indicating that the effect of Contextual Constraint was dependent upon whether the pre-target word had been fixated or skipped. In order to determine the nature of the interaction, further analyses were conducted in which the data-sets were restricted to cases in which the pre-target word was skipped or not. When the data-set was restricted in this manner, the number of observations for the cases where zone 3 was fixated were 1545 compared to 297 for cases where zone 3 was skipped. Consequently, the reader should bear in mind that the analyses involving the skip data are derived from a fairly small proportion of the data-set.

The effect of Preview in go-past was significant when the pre-target word had been skipped and also when it had been fixated. However, the effects in go-past were weaker when the pre-target word had been skipped, and in gaze, the effect of Preview was only apparent when the pre-target word had been fixated. This pattern of data is therefore consistent with that from the previous experiment and follows the same logic: The nature of the Preview would be less likely to influence inspection times on the target word in cases where the pre-target word was skipped given that the decision to skip the target word would have been made during fixation of a region prior to the pre-target word.

Partitioning the data-set into cases in which the pre-target word had been skipped or not, further revealed that measured Plausibility exerted a significant effect in go-past when the pre-target word had been skipped. The effect is a negative one, meaning that go-past durations increased as sentence Plausibility decreased. This outcome implies that a bigger effect of local sentence meaning was obtained when fixations on adjoining words did not account for some of the variance.

Despite the Contextual Constraint by Skipping Rate (zone 3) interaction obtained in go-past, there was no significant effect of Contextual Constraint in either the cases where the pre-target word had been skipped or in the cases where the pre-target word had been fixated. Somewhat dissimilarly to the outcome of the previous experiment therefore, there is no evidence to suggest that the effect of Contextual Constraint is dependent upon fixation of the prior word. Thus, presumably the interaction here just reflects a stronger (albeit non-significant) effect of Contextual Constraint in one case, but is nonetheless present in both cases.

Since there was no main effect of Contextual Constraint when the Contextual Constraint by Skipping Rate (zone 3) interaction was included in the model and since further analysis of this interaction did not shed any more light on the nature of the effect, it was worthwhile re-running the analyses with the Contextual Constraint by Skipping Rate (zone 3) interaction removed from the model (see Appendix M for correlations between the set of independent variables). Table 8.9 shows that with the interaction removed, the effect of Contextual Constraint was significant in go-past and near significant in gaze.

Table 8.9. Regression coefficients, standard errors and *t*-values for the Final Model (number of obs = 1842) with go-past and gaze (both in ms) as the dependent variables. Significance is estimated from tables of the *t* statistic assuming df = ∞ (i.e. values > 2.0 significant at p = 0.05)

Go-past duration as dependent variable				Gaze duration as dependent variable			
	Estimate	**Standard Error**	**t value**		**Estimate**	**Standard Error**	**t value**
Intercept	379.75	47.44	8.00	Intercept	245.08	29.26	8.34
Ctxt. Con.	-0.43	0.17	-2.57	Ctxt. Con.	-0.18	0.10	-1.73
Preview	34.85	10.82	3.22	Preview	17.90	6.66	2.69
Plausibility	-13.26	8.06	-1.65	Plausibility	1.92	4.81	0.40

Note: Ctxt. Con. = Contextual Constraint.

8.4. General Discussion of Experiment 5

The aim of this chapter was to determine whether the target-predictability effects obtained so far are the result of a contextual facilitation of lexical access of the target word or whether they are driven by a process of semantic integration. Since predictability effects have, so far, shown up not only on the critical word but also in regions preceding the critical word, it was also necessary to examine whether these effects relate to lexical access of the critical word.

In Chapter 6 there was evidence of very early effects of context and it was shown that these could not have been ones relating to lexical access of the critical word since this word was a long way from the current point of fixation. Instead, it was argued that the effects could plausibly have been related to a process of word-anticipation in which readers generate predictions about an up-coming critical word when the sentence is high-constrained towards a particular word or sub-set of words. It should be recalled that in Chapter 6, fixation durations in zone 2 were inflated in more constraining sentences, an outcome which would be compatible with this hypothesis. However, in Chapter 7, the effects obtained in zone 2 were not in the same direction as those shown in Chapter 6, suggesting that they were unlikely to be due to a process of word-anticipation. Additionally, the effects obtained in the previous experiment were also apparent later in the eye-movement record, meaning that they could have plausibly been related to lexical access of the critical word. Thus, it was necessary to determine whether early effects are necessarily related to lexical access of the critical word or whether they are instead related to higher-level sentential processes.

While the present study showed hints of relatively late effects of contextual constraint in zone 2, there was no evidence to suggest that these were dependent upon the nature of the target-preview, this suggests that the effects obtained here and in the latter two experiments were not related to lexical access of the critical word. Thus, it appears to be the case that the zone 2 effects are related to higher-level sentential processes as opposed to lexical processing of the critical word. However, since the content of the sentences differ within items at this point, it is difficult to determine the specific high-level processes which give rise to the effects. It might have been possible to speculate that the effects are driven by a word-anticipation process (for example), but it is not clear whether, generally speaking, inspection times increase or decrease, the more constraining the sentence context, thus making it even more impossible to make such an inference. Thus, the most parsimonious conclusion regarding very early effects of predictability is that they are related to high-level processing associated with the contextual constraint of the sentence as opposed to lexical processing associated with the critical word. This outcome is of course difficult to reconcile with both the *E-Z Reader* and SWIFT models of eye-movement control since the way in which predictability is instantiated in both models means that neither model can account for such early 'high-level' effects.

One of the primary aims of this study was to further investigate whether pre-target predictability effects (e.g. Kliegl et al., 2006; Kennedy et al., submitted, Chapter Six, this thesis) are partly driven by parafoveal lexical access of the up-coming word. In the preceding chapter, an orthodox effect of predictability was obtained on the pre-target word even though the target word was masked while in parafoveal vision. On first reflection, this outcome may appear to provide evidence against a version of the cued memory retrieval hypothesis which entails parafoveal processing of a predictable word, yet the effect in the masked condition did not appear to be related to high-level sentential processes only, since the same type of effect was not apparent in the unmasked condition. Instead, the effect appeared to be a consequence of the target-preview-mask. Additionally, there was a hint of an inverted effect in the unmasked condition, as well as evidence suggesting that different processes were operating in the unmasked and masked conditions, thus it was necessary to further investigate whether pre-target predictability effects relate to parafoveal lexical access.

The present results showed that there was no effect on the pre-target word for when the target-preview varied in predictability or was a semantically related word. Thus, the present study did not replicate the inverted predictability effect obtained in Chapter 6, and since there was only a hint of an inverted effect in the unmasked condition in Chapter 7, this means that when taken together, chapters 7 and 8 have provided evidence against both forms of the cued memory retrieval hypothesis. These outcomes, together with the fact that the effect obtained in the masked condition of the previous experiment was not related to higher-level processing, means that the nature of the (albeit non-significant) inverted effect of predictability obtained in Chapter 6, as well as those effects obtained in the previous studies cited, is still unidentified. The previous studies which have reported pre-target effects (e.g. Kliegl et al., 2006; Kennedy et al., submitted), were both corpus analysis studies, meaning that the nature of the sentence preceding the defined critical word would not have been controlled in those analyses. That is, it could be argued that the pre-target effect obtained in those studies arose due to variations in the content of the sentence preceding the target word. However, this cannot explain why the same effect was obtained in a controlled experiment in Chapter 6. Thus, whether the inverted effects reported in Chapter 6 and in the previous studies, relate to a parafoveal access of the critical word, or whether they are instead driven by processes operating at the level of the sentence, is open to debate.

The primary goal of this study was to determine whether predictability effects apparent on a critical word are related to lexical access of this word. It should be recalled that an interactive-activation type process of word recognition (e.g. McClelland & O'Regan, 1981) proposes that contextual and parafoveal information is used to drive lexical access, suggesting that predictability effects are related to a contextual facilitation of lexical access of the critical word. However, effects of predictability were obtained here even when the critical word did not vary in predictability, thus providing solid evidence to suggest that the effects are not driven by a contextual facilitation of lexical access of the critical word. Instead, it appears that predictability effects are actually effects of semantic integration arising from whether the context is constrained towards a particular semantic domain. More specifically, it is likely that it is more difficult to integrate the critical word into the global meaning of the sentence when the sentence is less constrained towards a particular semantic domain. There are two reasons for this proposal. First, if we compare the critical words employed here (e.g. 'estate') with the critical words employed in the latter two experiments (e.g. 'garden'), it is clear that they are both within the same semantic domain. Second, the pattern of effects obtained in the present study did not differ significantly from those obtained in the latter two experiments in which the critical word differed but the contextual constraint of the sentence did not. This means that the present outcome is more in-line with the assumption that lexical access is autonomous (e.g. Forster, 1979).

The proposed account of predictability effects also has a number of other important theoretical implications. First, the present outcome suggests that predictability may act like plausibility effects. This is because, recent research (e.g. Patson & Warren, 2010) suggests that plausibility effects appear to arise due to a difficulty with integrating a critical word or phrase into the overall meaning of the sentence, when the critical word or phrase is inconsistent with the global sentence meaning. It should be recalled from Chapter 2 that Patson and Warren tracked reader's eye-movements as they read sentences in which the critical word was either plausible (1a) or implausible (1b) and (1c) given the preceding sentence context. Additionally, the local propositions within the implausible sentences were either thematically related to the critical word ('infant') as in (1b) or were non-thematically related (1c).

(1a) "Bryan used a bottle to feed the hungry *infant* yesterday morning."

(1b) "Bryan used a bottle to fight off the hungry *infant* yesterday morning."

(1c) "Bryan used a trough to feed the hungry *infant* yesterday morning."

Patson and Warren found that inspection times were longer in both (1b) and (1c) than in (1a). This effect did not appear to be related to a contextual facilitation of the critical word, as the authors further showed that inspection times on the critical word were not influenced by whether the local proposition and critical word were thematically related or not. That is, fixation durations on the critical word did not differ in sentences (1b) and (1c), meaning that there was no evidence for intra-lexical priming. Overall, Patson and

Warren's data therefore suggest that target-plausibility effects arise due to difficulty with integrating implausible words into the global meaning of the sentence.

Whilst the critical words employed in the present study were not inconsistent with the meaning of the preceding sentence frame, it is likely that when the sentence context is less constrained towards a particular semantic domain, the global meaning of the sentence is less apparent. Thus, it is plausible that similar types of semantic integration processes give rise to both predictability and plausibility effects. The fact that throughout this thesis, 'predictability' effects have been apparent in first fixation durations, and because Patson and Warren found a near-significant effect of plausibility in first fixations, further implies that the process of semantic integration must occur fairly rapidly and that the measure of first fixation duration captures more than lexical access of a word.

As well as being incompatible with interactive-activation type models of word recognition, the suggestion that predictability effects on the critical word are actually effects of semantic integration occurring at the post-lexical stage, is incompatible with every other suggestion that contextual constraint affects lexical access. However, the proposal is particularly problematic for both the *E-Z Reader* and the SWIFT models since it would mean that the predictability variable entered into the models is invalid and therefore that simulations of these models is in fact picking up on some other variable. However, it should be recalled from Chapter 1, that the latest version of *E-Z Reader* (10) can now account for plausibility effects, thus if predictability effects are similar in nature to plausibility effects, then theoretically, *E-Z Reader* should be able to account for predictability effects.

In *E-Z Reader* 10 (Reichle, Warren & McConnell, 2009), a post-lexical integration stage is incorporated into the model in order to reflect integration processes such as incorporating a word's meaning into the syntactic structure or overall meaning of the sentence. In order to test the validity of the post-lexical integration stage, Reichle, Warren and McConnell (2009) carried out simulations of *E-Z Reader* 10 using the Schilling, Rayner and Chumbley (1998) data-set and Warren and McConnell's (2007) experimental data. By way of an eye-tracking study, Warren and McConnell (2007) showed that both gaze durations and total reading times were shorter on a plausible and possible critical word (2a) given the meaning of the preceding sentence frame, than on an implausible but possible critical word (2b). That is effects of plausibility were apparent but only in later eye-movement measures. Additionally, first fixation durations were longer on implausible and impossible critical words (2c) than on the critical words in 2b, revealing an early effect of possibility or selectional restriction violation.

(2a) "The man used a strainer to drain the thin *spaghetti*...."

(2b) "The man used a blow-dryer to dry the thin *spaghetti*..."

(2c) "The man used a photo to blackmail the thin *spaghetti*..."

In order to simulate Warren and McConnell's possible-implausible condition, the duration of the post-lexical integration stage on the target word was increased to 200ms to reflect post-lexical processing difficulty that might occur when readers generate a discourse model for an implausible event. To simulate the impossible-implausible condition, the duration of the post-lexical integration stage on the target word was also increased to 200ms, while the rate of lexical processing was attenuated by the selectional restriction violation. Simulations of *E-Z Reader* 10 showed that the model could simulate the correct pattern of effects. That is, similarly to Warren and McConnell's data, the model predicted an effect of plausibility in both gaze durations and total reading times, as well as an effect of selectional restriction violation in first fixations. However, and similarly to Warren and McConnell's data, the model did not predict an effect of plausibility in first fixations. Thus, while the model has made some progress in accounting for high-level semantic integration processes, it cannot account for the immediate post-lexical integration effects suggested by the Patson and Warren (2010) and present data-sets.

Whilst it is likely that the post-lexical integration stage of the E-Z Reader model could be tweaked to account for more immediate effects of post-lexical semantic integration effects, it is clear that the model would have to be drastically revised in order to account for the proposal that predictability effects are actually those relating to post-lexical semantic integration. That is, it would no longer be relevant to predict that predictability influences either L_1 or L_2. It has been proposed previously in this thesis that the fact that predictability and frequency appear to exert additive effects on fixation durations (e.g. Rayner et al., 2004; Altarriba et al., 1996; Lavigne et al., 2000; Rayner et al., 2001; Ashby, Rayner & Clifton, 2005; Kennedy, Pynte, Murray & Paul, submitted; Chapters 4 & 5, this thesis), could be due to the variables affecting the same process but not interacting with each other. Alternatively, it could be that the variables affect different processes and this conclusion seems more plausible given the present outcome. That is, it is highly likely that whilst the frequency effect is related to lexical access, the predictability effect is related to post-lexical integration.

To summarise, this study has provided evidence suggesting that very early effects of predictability are driven by high-level sentential processes. When the eyes were on the word prior to the target word, there was no evidence for any pre-target effects at all, thus whether some form of cued memory retrieval can account for the inverted effects shown in previous studies is still open to debate. The most significant finding was that the target-predictability effects shown in this thesis appear to be those relating to post-lexical semantic integration, an outcome which is more in-line with the idea that the process of lexical access is autonomous.

Chapter 9:

General Discussion

9.1. Introduction

The primary aim of this thesis was to identify the mechanism underpinning predictability effects. Throughout this thesis, predictability effects were obtained not only on the critical word but also in regions prior to the critical word, meaning that it also became necessary to determine whether the nature of the predictability effect differs depending upon where in the sentence the effect is obtained. Thus, the following discussion will consider the predictability effects which were apparent, and the processes which appear to give rise to them, as the reader parsed their way through a sentence.

A secondary aim of this thesis was to determine whether there was any evidence for distributed processing in reading. That is, the question of whether more than one word might be processed simultaneously. Thus the evidence which bears on this issue will also be considered.

9.2. The nature of early predictability effects

Effects of the measured cloze predictability of a given target word were obtained in the region[1] prior to the pre-target word in most of the experiments reported in this thesis. The primary issue was whether effects apparent in this region were associated with lexical processing of the critical word, or whether they were driven by higher-level sentential processes. In each of the experiments, the early zone always

[1] For the sake of convenience, the region prior to the pre-target word will henceforth, be referred to as the ‘early’ zone or region.

comprised three words, and the distance between the first character of the first word comprising the early zone and the first character of the critical target word, was always at least 20 characters (including character spaces) on average. Given that the perceptual span in reading is usually taken to extend for about 19 characters: 4 to the left and 15 to the right of fixation (e.g. McConkie & Rayner, 1975; Rayner, 1986; Rayner & Bertera, 1979), this means that any effects which were apparent fairly early on in the eye-movement record (e.g. in first fixation durations) were likely to have been obtained while the critical word was out-with the readers' visual or attentional span, and therefore are very unlikely to have been driven by lexical processing of the critical word.

Since the predictability effects obtained in the early region varied between experiments, it is worthwhile considering the pattern of effects obtained in each experiment. In Chapter 4, final fixation durations were (non-significantly) shorter when the preview of the critical word was predictable and misspelled. This outcome suggested that the eyes were attracted to the critical word when it was predictable and misspelled, and therefore that the effect may have been the result of a long-range parafoveal-on-foveal effect stemming from sub-lexical properties of the critical word. Such long-range parafoveal-on-foveal effects have previously been reported in the literature. For example, Kliegl, Risse and Laubrock (2007) have shown that gaze durations on a currently fixated word (n) are significantly shorter when the preview of $n + 2$ is a non-word than when it is an actual word, an outcome which is compatible with the present results. Additionally, Kennedy, Murray and Boissiere (2004) provide evidence to suggest that the orthographic properties of a word, when presented in a short sentence in a single line, can affect previous inspection times as far as 15.2 characters 'downstream'. However, the effect shown in Chapter 4 was not replicated in Chapter 5, when the preview of the critical word was more severely misspelled. If the effect in Chapter 4 (which was not wholly reliable) was psychologically real, then a larger effect should have been obtained when the misspelling was more severe. Since this was not the case, the most parsimonious conclusion regarding the outcome of these two experiments, is that they do not reveal anything informative regarding the nature of early predictability effects, and will therefore not be considered further.

In Chapter 6, in which four levels of predictability were employed so that sentences were either more or less constrained towards a particular word, first fixation durations were inflated in more constraining sentences. It was proposed that this outcome would be compatible with a process of word-anticipation in which readers generate predictions about an up-coming critical word when the sentence is highly-constrained towards a particular word or sub-set of words. However, the results in Chapter 7 provided evidence against this hypothesis since the early effects of predictability which were reported in that chapter, for identical sentence fragments, were not in the same direction as those reported in Chapter 6. That is, in Chapter 7, fixation durations were shorter when the target-word was low-predictable, and this outcome was dependent upon whether the target-preview was available for processing or was masked using a pixel scrambling technique. Additionally, this effect was also apparent later in the eye-movement record (e.g. in gaze and re-reading times), meaning that the critical word could have plausibly been within the readers' attentional span at this point and that the effect could have been the result of a long-range parafoveal-on-foveal effect stemming from the predictability of the critical word.

In order to help clarify whether these early effects of predictability obtained in Chapters 6 and 7, related to lexical processing of the critical word or not, in Chapter 8 the same sentence fragments were employed but the target-preview was manipulated so that it was either more or less predictable depending upon the preceding sentence frame, or was a non-predictable but semantically related plausible word. The rationale was that if a predictability by preview interaction was obtained in the early zone, then this would provide solid evidence to suggest that early effects of predictability are related to lexical processing of an up-coming critical word. The results provided hints of relatively late effects of contextual constraint (e.g. in re-reading times) yet there was no evidence to suggest that these were dependent upon the nature of the target-preview, suggesting that the early effects obtained in the prior studies were not long-range parafoveal-on-foveal effects.

The results reported in Chapter 8 suggest that early predictability effects are driven by higher-level sentential processes, as opposed to lexical processing associated with the critical word. Of course, the content of zone 2 differed across items, meaning that it is difficult to determine the specific high-level processes which give rise to the effects. Nevertheless, since the same experimental sentences were employed in experiments 3-5, this means that it should have been possible to obtain a similar pattern of effects across experiments, and such an outcome would have made it possible to at least draw some conclusions regarding the likely nature of the effects. However, the pattern of effects reported in Chapters 7 and 8 differed from those obtained in Chapter 6, as well as from each other, thus there was no consistent evidence for a process of word-anticipation which would likely predict the same pattern of effects in each experiment (at least for the cases where the up-coming target word was visible and varied in predictability).

One possible explanation is that the early effects reflect local semantic integration difficulty. If this hypothesis is true, then the effects can potentially be accounted for by revisions to the *E-Z Reader* model. Although *E-Z Reader* proposes that the engine driving eye-movements during reading is lexical access, *E-Z Reader* 10 (Reichle, Warren & McConnell, 2009) can now account for some high-level processing effects associated with the integration of the meaning of a word after it has been accessed, into the wider discourse of the sentence. However, the model would not be able to account for the effects which were obtained in first fixation durations on the early region in Chapter 6. This is because the model only predicts such effects to occur in later eye-movement measures (e.g. in gaze and total reading times). The idea that a process of semantic integration could account for the early predictability effects is in fact unlikely to be true anyway. This is because, such a process cannot account for the differing pattern of effects obtained between experiments. That is, if there was more difficulty with integrating the meaning of the early zone into the meaning of less-constraining sentences (for example), then it would be expected that fixation durations would be inflated in the less-constraining conditions in each of the experiments.

A more likely explanation for the differing pattern of effects is that readers adopted different processing strategies in each of the three experiments. This is plausible given that the latter two experiments included different preview manipulations whilst there was no preview manipulation in the experiment reported in Chapter 6. For example, it is possible that readers were aware of the contingent display change in the latter two experiments, and that the nature of these changes influenced reading strategy in those experiments. It is also possible that in the experiment in Chapter 8, readers adopted a specific strategy when it was becoming clear that the critical target word was never the word predicted by the sentence.

Overall, early effects of predictability appear to be driven by high-level processes operating at the sentence level. Since these processes do not appear to be related to semantic integration, this outcome is difficult to reconcile with the *E-Z Reader* model. Additionally, the present conclusions are out-with the range of factors that SWIFT considers.

9.3. Is the reading process serial or parallel in nature?

An on-going debate in the literature is whether the reading process is primarily serial or parallel in nature, and one of the aims of this thesis was to address this issue. The debate initially came about when parafoveal-on-foveal effects, which are now taken as evidence for parallel processing, were first reported by Kennedy (1995;1998; Murray & Rowan, 1998), and since then a significant amount of research has been conducted in order to help resolve the serial/parallel processing debate. Each of the experiments reported in this thesis investigated whether there was any evidence for parafoveal-on-foveal effects, and therefore parallel processing in reading.

There is now a large body of literature which suggests that both ‘high-level’ properties and ‘low-level’ properties of an as-yet-unfixated word can influence inspection time on a currently fixated word. High-level parafoval-on-foveal effects include those relating to the frequency of an as-yet-unfixated word (e.g. Kennedy & Pynte, 2005; Pynte & Kennedy, 2006; Kennedy, Pynte & Ducrot, 2002; Kennedy, 2000a, 2000b; Underwood, Binns & Walker, 2000). Whereas low-level effects include those relating to the informativeness[2] (e.g. Kennedy, 1995; Kennedy, 1998; Inhoff, Starr & Shindler, 2000b; Underwood, et al., 2000; Kennedy, 2000, 2000b; Kennedy, et al., 2002; Kennedy & Pynte, 2005; Pynte & Kennedy, 2006), or the familiarity[3] of an as-yet-unfixated word (e.g. Pynte & Kennedy, 2006; Pynte, Kennedy & Ducrot, 2004). High-level parafoveal-on-foveal effects cannot be accounted for by a serial model. This is because, attention always moves forward in the model (except for cases in which a regression is made), meaning that it is not possible for high-level properties of a parafoveal word, such as frequency or predictability, to influence processing on a currently fixated word. However, low-level parafoveal-on-foveal effects are not necessarily at odds with a serial processing viewpoint. This is because, the *E-Z Reader* model now includes an early pre-attentive visual processing stage of word-encoding in which low-spatial-frequency visual information from across the whole page can be acquired and processed in parallel. More specifically, the *E-Z Reader* can account for low-level effects since it is proposed that, when viewing position is close, orthographic properties of parafoveal words can be concurrently processed in a manner which does not require attention (e.g. Pollatsek, Reichle & Rayner, 2006).

The experiments reported in chapters 4 and 5, provided evidence for low-level parafoveal-on-foveal effects. In both experiments, the pre-target word was inspected for longer when the target-preview was misspelled. This outcome is incompatible with the idea that irregular letter sequences ‘pop out’ and attract the eyes (e.g. Hyona & Bertram, 2004). More specifically, this ‘magnetic attraction’ hypothesis predicts

[2] Informativeness (or type frequency) refers to the number of different words of the same length consistent with the initial letters of the word in question. Thus an informative word is one which shares its initial three letters with very few words.

[3] Familiarity (or token frequency) refers to the cumulative lexical frequency of all words of the same length sharing the initial three letters of the word in question (thus an orthographically familiar word is one which shares its initial three letters with a large number of other words).

that inspection times on a foveal word should be shorter when a parafoveal word is misspelled, an outcome previously shown by Pynte et al., (2004). The present results are instead compatible with the suggestion that when a misspelled word is in parafoveal vision, this causes the eyes to stay and fixate the foveal word, although, as noted above, the exact masking and boundary manipulations employed may turn out to be critical.

There was no evidence of any parafoveal-on-foveal effects relating to frequency in the experiments reported in either chapters 4 or 5 (the frequency of the target word was manipulated in these experiments), an outcome which differs from many recent studies which have provided evidence for such effects (e.g. Kennedy & Pynte, 2005; Pynte & Kennedy, 2006; Kennedy, Pynte & Ducrot, 2002; Kennedy, 2000a, 2000b; Underwood, Binns & Walker, 2000). There is in fact evidence in the literature to suggest that frequency effects are only obtained in laboratory studies when the foveal word is short. That is, when the foveal word is long, lexical frequency of the parafoveal word does not affect foveal processing since not enough of the parafoveal word is visible. Instead, the initial familiarity or informativeness of the parafoveal word exerts an effect on foveal processing, especially if the parafoveal word is also long (e.g. Pynte & Kennedy, 2006; Kennedy & Pynte, 2005; Kennedy, et al., 2002; Kennedy, 1998). However, the above explanation is unlikely to be able to account for the fact that no pre-target frequency effects were obtained, since in the experiments employed in chapters 4 and 5, the pre-target words were short-medium in length (mean = 4.9 characters), whilst the target words were also not particularly long (mean = 5.6 characters). Thus, and contrary to Kennedy and Pynte’s suggestion, it does not appear to be the case that parafoveal-on-foveal frequency effects are only obtained when the foveal word is short.

One possible explanation for this discrepancy, however, is that since in the present experiments, the preview of the parafoveal word was misspelled in half of the cases, this would have prevented parafoveal-on-foveal effects of frequency from being obtained in these misspelled preview conditions. Of course, there was no evidence of parafoveal-on-foveal frequency effects in the correctly spelled preview conditions only, but this outcome may have been due to a lack of power.

While it seems clear that the results of the experiments reported here do not provide evidence that the frequency of a parafoveal word can influence foveal inspection times, there is evidence derived from the preview manipulations that orthographic properties of a parafoveal word can influence inspection strategy on a currently fixated word. Taken together, these outcomes do not, however, provide critical evidence for or against either the *E-Z Reader* and SWIFT models since both models can account for low-level parafoveal-on-foveal effects, and since a lack of parafoveal-on-foveal frequency effects does not necessarily provide evidence against parallel processing in reading. Thus, the remainder of this section will concentrate on the nature of the pre-target effects of predictability which were shown, as these can potentially allow a critical distinction to be made between the two models.

In chapters 4 and 5, there was no evidence of any parafoveal-on-foveal effects of predictability, although in the experiment reported in Chapter 6, an inverted effect of predictability was obtained on the pre-target word. Such an effect has previously been reported in the literature (e.g. Kliegl, Nuthmann & Engbert, 2006; Kennedy, Pynte, Murray & Paul, submitted), and if it is a true parafoveal-on-foveal effect, then it is of theoretical significance, since it would provide evidence of parallel processing in reading.

If the inverted effect reported in Chapter 6 was a genuine parafoveal-on-foveal effect, this would mean that the pre-target and target words were processed together, and therefore that inspection strategy on the pre-target and target words should have been similar. However, inspection strategy on these words significantly differed from each other, thus implying that different processes were operating during the inspection of each of these words, and therefore that the inverted effect could not have been a parafoveal-on-foveal effect. An alternative explanation for the inverted effect is that it was the result of mislocated fixations. According to the mislocated fixation proposal (e.g. Drieghe, Rayner & Pollatsek, 2008), saccades that undershoot the intended target word could give rise to apparent parafoveal-on-foveal effects since in these cases, although fixation is on the pre-target word, it is actually the target word that is being processed. According to this theory therefore, any predictability effect obtained on the pre-target word should actually be a target-word effect, and as a consequence, the direction of the pre-target predictability effect should be in the same (orthodox) direction as target-predictability effects. However, given that the predictability effect was in fact inverted, means that it cannot be the result of mislocated fixations either.

A possible interpretation of such an inverted predictability effect is that it arises due to a process of cued memory retrieval (e.g. Kliegl, et al., 2006). That is, readers may anticipate an up-coming word (*n*) if the sentence is heavily constrained towards it and will retrieve the as-yet-unfixated word from memory during fixation of the prior word (*n*-1). An alternative version of this hypothesis suggests that if the reader has anticipated an up-coming predictable word (*n*) and if the initial letters of the word (while it is in parafoveal vision) match the reader's expectation, then the reader may begin to retrieve the predictable word from memory during fixation on the prior word, using both the initial letters of the parafoveal word and prior sentence context as retrieval cues. Both versions of the cued memory retrieval hypothesis therefore predict inflated fixation durations on a currently fixated word when the up-coming word is predictable, and also imply that processing strategies on the pre-target and target words should differ. Thus, either version of this hypothesis is able to explain the pattern of effects shown in Chapter 6.

In the experiment reported in Chapter 7, in which the sentence fragments were the same as in Chapter 6, but which employed a pixel masking scrambling technique so that the preview of the target word was either masked or available for processing, there was only a hint of an inverted effect in the unmasked condition. Chapter 7 also revealed an orthodox effect of predictability in the masked condition but this appeared to be a consequence of the target-preview-mask. The subsequent experiment employed the same materials as those used in chapters 6 and 7 but replaced the masked condition with a non-predictable but semantically related and plausible target-preview. The outcome was that there was no evidence for any effects on the pre-target word at all. Thus, the fact that no significant inverted effect was obtained in either chapters 7 or 8 for when the target-preview varied in predictability and was available for processing, meant that neither experiment provided evidence for a process of cued memory retrieval which involves parafoveal processing of a predictable word.

An alternative explanation is that the mechanism underpinning inverted effects of predictability is one related to pure word-anticipation which does not involve memory retrieval. However, since there was no effect in the non-predictable preview condition in Chapter 8, and since the effect in the masked condition in Chapter 7 appeared to be a consequence of the target-preview-mask, this does not provide any evidence to suggest that the effect reported in Chapter 6, as well as those effects obtained in previous studies (e.g. Kliegl et al., 2006; Kennedy et al., submitted) is one relating to either a process of pure word-anticipation or a process of cued memory retrieval in which there is no perceptual processing of the parafoveal word.

Since the studies (e.g. Kliegl et al., 2006; Kennedy et al., submitted) which have reported pre-target effects of predictability were both corpus analytic studies, the nature of the words preceding the defined critical word would not have been controlled in those analyses. Thus, one possibility is that the pre-target effect obtained in those studies arose due to variations in the content of the sentence preceding the target word. However, this explanation cannot account for the effect shown in the controlled experiment reported in Chapter 6.

Thus, whether the inverted effects reported in Chapter 6 and in the previous studies, relate to a parafoveal access of the critical word, or whether they are instead driven by high-level sentential processing is clearly still open to debate. It is more likely however, that the effects are related to high-level sentential processing. This is because, whilst the experiments reported in Chapters 7 and 8 suggested that the effect is not related to the parafoveal access of a critical word, a full investigation into whether the effect is related to higher-level sentential processing was not conducted. In order to provide a thorough investigation into whether or not pre-target predictability effects are related to higher-level processes, it will be necessary to conduct further studies in which the content of the sentences preceding the critical word are varied as opposed to the nature of the target-preview.

What can be concluded, however, is that since the pre-target predictability effect shown in Chapter 6 is unlikely to be the result of a genuine parafoveal-on-foveal effect (because different processing strategies appeared to be operating on these words), and since there was no other evidence of high-level parafoveal-on-foveal effects, this thesis has not provided evidence against serial processing in reading.

9.4. The nature of target-predictability effects

The motivation behind this thesis was to identify the nature of the predictability effect shown in fixation durations on a critical word. Whilst there are plenty of studies which provide evidence for predictability effects (e.g. Rayner, Ashby, Pollatsek & Reichle, 2004; Binder, Pollatsek & Rayner, 1999; Altarriba, Kroll, Sholl & Rayner, 1996; Frisson, Rayner & Pickering, 2005; Lavigne, Vitu & d'Ydewalle, 2000; Rayner & Well, 1996; Balota, Pollatsek & Rayner, 1985; Calvo & Meseguer, 2002; Ehrlich & Rayner, 1981; Inhoff, 1984), it is clear that the precise factors underlying these effects is still unknown. Thus, the experiments reported in this thesis investigated possible mechanisms which may underpin the predictability effect.

It should be recalled that the early Hypothesis Testing and Guessing Game models of reading (e.g. Goodman, 1967; Haber, 1978; Hochberg, 1978; Levin & Kaplan, 1970; Smith, 1971) suggest that during the fixation of a current word (*n*), readers form predictions about what the next word (n + 1) will be, based on a combination of the contextual information provided by the sentence and parafoveal preview information. When n + 1 is eventually fixated, the prediction is subsequently confirmed or disconfirmed. This theory could potentially account for the predictability effect since presumably fewer words are predicted when contextual constraint is high than when it is low, meaning that when the target word is eventually fixated, it will take less time for a match to be made between the generated lexical candidates and the correct target word. One of the main criticisms of this theory, however, relates to the fact that average cloze task results appear to show that we are only good at guessing very predictable words, meaning that if we do make predictions during reading, then most of these predictions will be incorrect and this is likely to produce interference effects.

Since, on average, only some words are guessed well, and if it is the case that there are interference effects during reading due to making incorrect predictions, then the Guessing Game models of reading would suggest that predictability effects should only be obtained when predictability is high. This means that the function relating predictability and fixation durations should not be a strictly monotonic decreasing one (where fixation times decrease as predictability increases), but should instead be a dog-leg function. However, it could of course be the case that we do make predictions about up-coming words and there is no penalty for incorrect guessing. If there is no penalty, then Guessing Game models may instead predict a monotonic relationship between predictability and fixation durations. Regardless of whether there is a processing penalty for incorrect guessing, Guessing Game models of reading would further predict that the availability of parafoveal preview information is critical for obtaining a predictability effect, since this information is used to make predictions about up-coming words.

In the experiment reported in Chapter 4, in which a preview manipulation was employed so that the preview of the target word (which varied in predictability), was either identical to the target word or misspelled, it was shown that the predictability effects did not differ according to preview condition. It is likely however, that readers were able to extract a relatively similar amount of useful parafoveal information in both preview conditions, and therefore that the extent of the misspelling was not severe enough in order to provide an adequate test of the word-prediction hypothesis.

In Chapter 5, which used the same sentence fragments as Chapter 4 but employed a more severely misspelled preview manipulation, the predictability effect disappeared. Thus, taken together, the experiments reported in chapters 4 and 5 provide evidence which would be compatible with the idea that readers form predictions about words based on contextual and parafoveal information.

In Chapter 6, it was further shown that predictability and fixation durations were monotonically related, an outcome which would be compatible with a process of word-prediction in which there is no penalty for incorrect guessing. However, this hypothesis was subsequently rejected in Chapter 7, since predictability effects were still apparent following the absence of initial parafoveal preview information. Of course, the outcome of the experiment reported in Chapter 7 differed from that reported in Chapter 5 in which the predictability effect was eradicated following a severely misspelled preview. However, it is certainly possible that the misspelling provided the reader with misleading information, meaning that the outcome of Chapter 5 was not due to an inability to make predictions, but was instead due to some form of interference effect. Thus, the pixel scrambling masking manipulation employed in Chapter 7 arguably provided a more ecologically valid test of the word-prediction hypothesis than the misspelled preview manipulation employed in Chapter 5, yet this experiment provided no evidence for the hypothesis.

In Chapter 7, the function relating predictability and fixation durations was again shown to be a monotonic decreasing one. This outcome, together with the fact that the predictability effects did not appear to be dependent upon the availability of parafoveal information, meant that the effects were also compatible with an interactive-activation type process of word recognition (e.g. McClelland & O’Regan,

1981) in which contextual and parafoveal information are both used to drive lexical access. It was possible to distinguish this theory from the word-prediction theory since although the former also predicts a graded effect of predictability, it additionally predicts that in the absence of parafoveal information, lexical access will simply be delayed until the word is eventually fixated, meaning that the availability of parafoveal information would not be critical for obtaining a subsequent predictability effect. Thus, in Chapter 7 it was concluded that based on the findings up to that point, the predictability effect could potentially be accounted for by an interactive theory of language processing.

The target-predictability effects reported in chapters 4-7 were also compatible with what might be expected from a process in which semantic integration of a word into the overall meaning of the sentence takes place after the word has been accessed (e.g. Forster, 1979). It was suggested that if the predictability effect is in fact one relating to post-lexical semantic integration, then whether the critical word is actually the predictable word or not may not matter. That is, a predictability effect may be obtained as long as the critical word is a semantically related and plausible word.

In the experiment reported in Chapter 8, in which the target word was a non-predictable but semantically related and plausible word, the pattern of predictability effects obtained did not differ significantly from those shown in chapters 6 and 7 in which the critical word differed but the contextual constraint of the sentence did not. This suggested that the mechanism underpinning the predictability effect is one relating to post-lexical semantic integration. More specifically, it is likely that it is more difficult to integrate the meaning of a critical word into the global meaning of the sentence when the sentence is less constrained towards a particular semantic domain, and therefore the overall meaning of the sentence is less apparent.

The proposed account of predictability effects has a number of important theoretical implications. First, the account is more compatible with the idea that lexical access is autonomous (e.g. Forster, 1979). This is because the results provide evidence against the idea that readers use context to generate a small number of lexical candidates (e.g. McClelland & O'Regan, 1981). Of course, the results are not necessarily at odds with a weak version of the interactive theory in which the nodes for a general class of words may be activated, thus resulting in a 'broader' facilitation of lexical access. However, it seems more likely that predictability effects are those relating to semantic integration, given that there is a growing body of literature which suggests that global contextual information, such as the nature of the critical word being described in the sentence, influences semantic interpretation on a critical word (e.g. Cook & Myers, 2004; Filik, 2008; Garrod & Terras, 2000; Hagoort, Hald, Bastiaansen & Petersson, 2004; Rayner, Warren, Juhasz and Liversedge, 2004; Murray & Rowan, 1998; Murray, 2005; Warren & McConnell, 2007; Patson & Warren, 2009).

Thus, it appears that predictability effects may act more like plausibility effects. Specifically, plausibility effects appear to be the result of a difficulty with integrating a critical word or phrase into the overall meaning of the sentence, when the critical word or phrase is inconsistent with the global sentence meaning. Although the critical words employed in the present study were not inconsistent with the meaning of the preceding sentence frame, it is likely that when the sentence context is less constrained towards a particular semantic domain, the global meaning of the sentence is less apparent, thus making integration of a critical word more difficult.

A further implication of the present results is that the process of semantic integration must occur fairly rapidly given that throughout this thesis predictability effects have been apparent in first fixation durations, and since there is also evidence in the literature to suggest that plausibility can exert an influence in first fixation durations (e.g. Patson & Warren, 2010). Furthermore, the fact that such effects have been shown in first fixations, suggests that this measure captures more than lexical access of a word.

As well as being incompatible with strong versions of interactive theories of word recognition, the suggestion that predictability effects on the critical word are actually effects of semantic integration occurring at a post-lexical stage, is particularly problematic for both the *E-Z Reader* and the SWIFT models which suggest that predictability influences lexical access. Of course, the latest version of *E-Z Reader* (Reichle, Warren & McConnell, 2009), now includes a post-lexical integration stage to reflect integration processes such as incorporating a word's meaning into the syntactic structure or overall meaning of the sentence. The reason for this implementation was to account for plausibility effects, thus if predictability effects are similar in nature to plausibility effects, then theoretically, *E-Z Reader* should be able to account for predictability effects.

However, it is apparent from simulations of the *E-Z Reader* model (e.g. Reichle et al., 2009), that it can only account for high-level semantic integration processes which occur later in the eye-movement record (e.g. in gaze and in total reading times); it cannot account for the immediate post-lexical integration effects suggested by the present data-sets and by the Patson and Warren (2009) study. It seems likely that the post-lexical integration stage of the *E-Z Reader* model could be tweaked to account for more immediate effects of post-lexical semantic integration effects, but it is unclear how the model (or indeed the SWIFT model) could cope with the proposal that predictability effects actually relate to post-lexical semantic integration rather than a factor that influences the speed of lexical access. That is, it would no longer be relevant to suggest that predictability influences the speed of lexical access.

The outcome of Chapter 8 also shed further light on the additive effects of frequency and predictability shown in Chapters 4 and 5 and in a number of previous studies (e.g. Rayner et al., 2004; Altarriba et al., 1996; Lavigne et al., 2000; Rayner et al., 2001; Ashby, Rayner & Clifton, 2005; Kennedy, Pynte, Murray & Paul, submitted). If Additive Factor's Logic (e.g. Sternberg, 1969) can plausibly be applied to fixation durations, then additive effects would suggest that two variables either affect different processes or affect the same process but do not interact. The present results suggest that it is likely that the variables affect different stages, with frequency influencing the initial stages of word-encoding, and predictability exerting its effect at a later post-lexical stage.

9.4. Conclusions

This thesis has provided evidence of very early effects of word predictability but it is highly likely that these are driven by high-level sentential processes. While low-level parafoveal-on-foveal effects were apparent in the results, there was no evidence of any parafoveal-on-foveal effects relating to either the frequency or the predictability of a critical word, meaning that there was not sufficient evidence to provide evidence against a serial account of the reading process. Overall, the most significant finding in this thesis was that target-predictability effects appear to be related to post-lexical semantic integration, rather than an effect of context on word recognition, an outcome which cannot be accounted for by either of the major models of eye movement control during reading, and which provides evidence which is more in-line with the idea that the process of lexical access is autonomous.

References

Altarriba, J., Kroll, J.F., Sholl, A., & Rayner, K. (1996). The influence of lexical and conceptual constraints on reading mixed language sentences: Evidence from eye fixation and naming times. *Memory & Cognition*, *24*, 477-492.

Angele, B., Slattery, T., Yang, J., Kliegl, R., & Rayner, K. (2008). Parafoveal processing in reading: Manipulating n+1 and n+2 previews simultaneously. *Visual Cognition*, *16*, 697-707.

Ashby, J., Rayner, K., & Clifton, C. Jr. (2005). Eye movements of highly skilled and average readers: Differential effects of frequency and predictability. *The Quarterly Journal of Experimental Psychology*, *58A*, (6), 1065-1086.

Balota, D.A. (1990). The role of meaning in word recognition. In D.A. Balota, G.B. Flores d'Arcais, & K.Rayner (Eds.), *Comprehension processes in reading* (pp. 9 – 32). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Balota, D.A., & Chumbley, J.I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 340-357.

Balota, D.A., Pollatsek, A., & Rayner, K. (1985). The interaction of contextual constraints and parafoveal visual information in reading. *Cognitive Psychology*, *17*, 364-390.

Balota, D. A., & Rayner, K. (1983). Parafoveal visual information and semantic contextual constraints. *Journal of Experimental Psychology: Human Perception & Performance*, *9*, 726-738.

Baayen, R.H., Piepenbrock, R., & Gulikers, L. (1995). *The CELEX Lexical Database*. [CD-ROM]. Philadelphia: Linguistic Data Consortium, University of Pennsylvania.

Bates, D., & Sakar, D. (2006). *Lme4: Linear mixed-effects models using S4 classes. R* *package* (Version 0.995-2). Vienna, Austria: R Foundation for Statistical Computing.

Becker, C.A. (1976). Allocation of attention during visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 556-566.

Becker, C.A. (1979). Semantic context and word frequency effects in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 252- 259.

Becker, C.A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. *Memory and Cognition, 8,* 439-512.

Beauvillain, C., & Doré, K. (1998). Orthographic codes are used in integrating information from the parafovea by the saccadic computation system. *Vision Research*, *38*, 115-123.

Beauvillain, C., Doré, K., & Baudouin, V. (1996). The “center of gravity” of words: Evidence for an effect of the word-initial letters. *Vision Research, 36,* 589-603.

Becker, W., & Jurgens, R. (1979). An analysis of the saccadic system by means of double-step stimuli. *Vision Research*, *19*, 967-983.

Besner, D., & McCann, R.S. (1987). Word frequency and pattern distortion in visual word identification and production. In M. Coltheart (Ed.), *Attention and performance XII: The Psychology of reading* (pp.201-209). Hillsdale, NJ: Erlbaum.

Binder, K., Pollatsek, A., & Rayner, K. (1999). Extraction of information to the left of the fixated word in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1162-1172.

Blanchard, H.E. (1985). A comparison of some processing time measures based on eye movements. *Acta Psychologica, 58,* 1-15.

Blanchard, H.E., McConkie, G.W., Zola, D., & Wolverton, G.S. (1984). Time course of visual information utilization during fixations in reading. Journal of Experimental Psychology: *Human Perception and Performance, 10,* 75-89.

Blanchard, H. E., Pollatsek, A., & Rayner, K. (1989). The acquisition of parafoveal word information in reading. *Perception & Psychophysics, 46,* 85-94.

Boston, M.V., Hale, J., Kliegl, R., Patil, U. & Vasishth, S. (2008). Parsing costs as predictors of reading difficulty: An evaluation using the Potsdam Sentence Corpus. *Journal of Eye Movement Research, 2(1):1,* 1-12.

Brysbaert, M., & Vitu, F. (1998). Word skipping: Implications for theories of eye movement control in reading. In G. Underwood (Ed.), *Eye guidance in reading and scene perception (pp. 125-147).* Oxford, England: Elsevier.

Calvo, M.G., & Meseguer, E. (2002). Eye movements and processing stages in reading: Relative contributions of visual, lexical, and contextual factors. *The Spanish Journal of Psychology, 5,* 66-77.

Camblin, C., Gordon, P.C., & Swaab, T.Y. (2007). The interplay of discourse congruence and lexical association during sentence processing: Evidence from ERPs and eye tracking. *Journal of Memory and Language, 56,* 103-128.

Carpenter, R.H.S. (2000). The neural control of looking. *Current Biology, 10,* R291-R293.

Carpenter, P.A., & Just, M.A. (1983). What your eyes do while your mind is reading. In K.Rayner (Ed.), *Eye movements in reading: Perceptual and language processes* (pp.275-307). New York: Academic Press.

Clark, V.P., Fan, S., & Hillyard, S.A. (1995). Identification of early visual evoked potential generators by retinoptic and topographic analyses. *Human Brain Mapping, 2,* 170-187.

Clifton, C., Jr. (1993). Thematic roles in sentence parsing. *Canadian Journal of Experimental Psychology*, *47*, 222-246.

Clifton, C., Traxler, M.J., Mohamed, M.T., Williams, R.S., Morris, R.K., & Rayner, K. (2003). The use of thematic role information in parsing: Syntactic processing autonomy revisited. *Journal of Memory and Language, 49,* 317-334.

Cook, A., & Myers, J.L. (2004). Processing discourse roles in scripted narratives: The influence of context and world knowledge. *Journal of Memory and Language, 50,* 268-288.

Dambacher, M., Kliegl, R., Hofmann, M., & Jacobs, A. (2006). Frequency and predictability effects on event-related potentials during reading. *Brain Research, 1084,* 89-103.

DeLong, K.A, Urbach, T.P., & Kutas, M. (2005). Probabilistic word pre-activation during language comprehension inferred from electrical brain activity. *Nature Neuroscience, 8,* 1117-1121.

Doré, K., & Beauvillain, C. (1997). Latency dependence of word-initial letter integration by the saccadic system. *Perception & Psychophysics*, *59*, 523-533.

Drieghe, D., Brysbaert, M., & Desmet, T. (2005). Parafoveal-on-foveal effects in text reading: Does an extra space make a difference? *Vision Research, 45,* 1693-1706.

Drieghe, D., Brysbaert, M., Desmet, T., & Debaecke, C. (2004). Word skipping in reading: On the interplay of linguistic and visual factors. *European Journal of Cognitive Psychology*, *16*, 79-103.

Drieghe, D., Rayner, K., & Pollatsek, A. (2005). Eye movements and word skipped during reading revisited. Journal of Experimental Psychology: Human Perception and Performance, 2005, 31, 954-969.

Drieghe, D., Rayner, K., Pollatsek, A. (2008). Mislocated fixations can account for parafoveal-on-foveal effects in eye movements during reading. *Quarterly Journal of Experimental Psychology*, 61, 1239-1249.

Ehrlich, S.F., & Rayner, K. (1981). Contextual effects on word perception and eye movements during reading. *Journal of Verbal Learning and Verbal Behaviour*, 20, 641- 655.

Engbert, R., Longtin, A., & Kliegl, R. (2002). A dynamical model of saccade generation in reading based on spatially distributed lexical processing. *Vision Research, 42,* 621-636.

Engbert, R., Nuthmann, A., Richter, E., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review, 112*, 777-813.

Erlhagen, W., & Schoner, G. (2002). Dynamic Field Theory of Movement Preparation. *Psychological Review, 109 (3),* 545-572.

Ferreira, F., & Clifton, C.J. (1986). The independence of syntactic processing. *Journal of Memory and Language, 25,* 348-368.

Filik, R. (2008). Contextual override of pragmatic anomalies: Evidence from eye movements. *Cognition, 106,* 1038-46.

Findlay, J.M., & Walker, R. (1999). A model of saccadic eye movement generation based on parallel processing and competitive inhibition. *Behavioral and Brain Sciences, 22,* 661-721.

Forster, K.I. (1976). Accessing the mental lexicon. In R.J. Wales & E.C.T. Walker (Eds.), *New approaches to language mechanisms* (pp. 257-287). Amsterdam: North Holland.

Forster, K.I. (1979). Levels of processing and the structure of the language processor. In W.E. Cooper & E. Walker (Eds.), *Sentence processing: Psycholinguistic studies presented to Merrill Garrett* (pp. 27-85). Hillsdale, NJ:Erlbaum.

Forster, K.I., & Chambers, S.M. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior, 12*, 627-635.

Forster, K.I., & Shen, D. (1996). No enemies in the neighbourhood: Absence of inhibitory neighbourhood effects in lexical decision and semantic categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 696-713.

Foxe, J.J., & Simpson, G.V. (2002). Flow of activation from V1 to frontal cortex in humans: A framework for defining “early” visual processing. *Experimental Brain Research, 142,* 139-150.

Frazier, L. & Rayner, K. (1982) Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology 14,* 178-210.

Frederiksen, J.R., & Kroll, J.F. (1976). Spelling and sound: Approaches to the internal lexicon. *Journal of Experimental Psychology: Human Perception and Performance*, *2*, 361-379.

Frisson, S., Rayner, K., & Pickering, M.J. (2005). Effects of Contextual Predictability and Transitional Probability on Eye Movements During Reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*, 862-877.

Garrod,S., & Terras, M. (2000). The contribution of lexical and situational knowledge to resolving discourse roles: Bonding and resolution. *Journal of Memory and Language*, *42*, 526-544.

Goodman, K.S. (1970). Behind the eye: What happens in reading. In K. Goodman & O. Niles (Eds.), *Reading: Process and program* (pp. 3-38). Urbana, IL: National Council of Teachers of English.

Haber, R.N. (1978). Visual perception. *Annual Review of Psychology, 29,* 31-59.

Hagoort, P., Hald, L., Bastiaansen, M.C.M., & Petersson, K.M. (2004). Integration of word meaning and world knowledge in language comprehension. *Science, 304,* 438-440.

Hale, J. (2001). A probabilistic Earley parser as a psycholinguistic model. In *Proceedings of the Second Meeting of the North American Chapter of the Association for Computational* Linguistics (pp. 1-8). Pittsburgh, PA: Carnegie Mellon University.

Hand, C.J., Miellet, S., O'Donnell, P.J., & Sereno, S.C. (2006) How word frequency and predictability effects are modulated by parafoveal preview during reading: Evidence from eye movements. *Poster presented at 12th Annual AMLaP Conference, Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands.*

Henderson, J.M., & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *16*, 417-429.

Henderson, J.M., & Ferreira, F. (1993). Eye movement control during reading: Fixation measures reflect fovel but not parafoveal processing difficulty. *Canadian Journal of Experimental Psychology*, *47*, 201-221.

Hill, R.L. & Murray, W.S. (2000). Commas and spaces: Effects of punctuation on eye movements and sentence parsing. In A. Kennedy, R. Radach, D. Heller & J. Pynte (Eds). *Reading as a Perceptual Process*. (pp. 565-589) Oxford: Elsevier.

Hirotani, M., Frazier, L., & Rayner, K. (2006). Punctuation and intonation effects on clause and sentence wrap-up: Evidence from eye movements. *Journal of Memory and Language,* 54, 425-443.

Hochberg, J.E. (1978). *Perception.* Englewood Cliffs, NJ: Prentice-Hall.

Hogaboam, T.W. (1983). Reading patterns in eye movements. In K. Rayner (Ed.), *Eye movements in reading* (pp.309-332). New York: Academic Press.

Howes, D.H., & Solomon, R.L. (1951). Visual duration threshold as a function of word-probability. *Journal of Experimental Psychology*, *41*, 401-410.

Hudson, P.T.W., & Bergman, M.W. (1985). Lexical knowledge in word recognition: Word length and word frequency in naming and lexical decision tasks. *Journal of Memory and Language, 24*, 46-58.

Huestegge, L., Grainger, J., & Radach, R. (2003). Commentary on Reichle, E.D., Rayner, K., & Pollatsek, A. The E-Z Reader model of eye- movement control in reading: Comparison to other models. *Brain and Behavioral Sciences, 26,* 445-476.

Hyönä, J. (1993). Effects of thematic and lexical priming on readers' eye movements. *Scandinavian Journal of Psychology*, *34*, 293-304.

Hyönä, J. (1995a). Do irregular letter combinations attract readers' attention? Evidence from fixation locations in words. *Journal of Experimental Psychology: Human Perception and Performance*, *21,* 68-81.

Hyönä, J., & Bertram, R. (2004). Do frequency characteristics of non-fixated words influence the processing of fixated words during reading? *European Journal of Cognitive Psychology, 16,* 104-127.

Hyönä, J., Bertram, R. & Pollatsek, A. (2004). Are long compound words identified serially via their constituents? Evidence from an eye-movement-contingent display change study. *Memory & Cognition, 32,* 523-532.

Hyönä, J., & Olson, R.K. (1995). Eye movement patterns among dyslexic and normal readers: Effects of word length and word frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 1430-1440.

Hyönä, J., & Pollatsek, A. (1998). Reading Finnish compound words: Eye fixations are affected by component morphemes. *Journal of Experimental Psychology: Human Perception & Performance, 24,* 1612-1627.

Inhoff, A.W. (1984). Two stages of word processing during eye fixations in the reading of prose. *Journal of Verbal Learning and Verbal Behavior*, *23*, 612-624.

Inhoff, A.W. (1989). Lexical access during eye fixations in reading: are word access codes used to integrate lexical information across interword fixations. *Journal of Memory and Language, 28,* 444-461.

Inhoff, A.W., Briihl, D., & Schwartz, J. (1996). Compound word effects differ in reading, on-line naming, and delayed naming tasks. *Memory & Cognition*, *24*, 466-476.

Inhoff, A.W., Pollatsek, A., Posner, M.I., & Rayner, K. (1989). Covert visual attention and extrafoveal information use during object identification. *Perception & psychophysics, 45 (3),* 196-208.

Inhoff, A.W., & Rayner, K. (1986). Parafoveal word processing during eye fixations in reading: Effects of word frequency. *Perception & Psychophysics*, *40*, 431-439.

Inhoff, A.W., Starr, M.S., & Shindler, K. (2000b). Is the processing of words during a fixation of text strictly serial? *Perception and Psychophysics, 62,* 1474-1484.

Irwin, D.E. (1998). Lexical processing during saccadic eye movements. *Cognitive Psychology, 36,* 1 -127.

Just, M.A., & Carpenter, P.A. (1978). Inference processing during reading: Reflections from eye fixations. In J.W. Senders, D.F. Fisher, R.A. Monty (Eds.), Eye Movements and the Higher Psychological Functions. Hillsdale, NJ: Erlbaum.

Just, M.A., & Carpenter, P.A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review*, *87*, 329-354.

Kamide, Y., Altmann, G.T.M., & Haywood, S.L. (2004). The time-course of constraint-application during sentence processing in visual contexts: Anticipatory eye-movements in English and Japanese. In M. Tanenhaus & J. Trueswell (Eds.), *World-situated language use: Psycholinguistic, linguistic and computational perspectives on bridging the product and action traditions*; MIT Press.

Kapoula, Z., & Robinson, D.A. (1986). Saccadic undershoot is not inevitable: saccades can be accurate. *Vision Research, 26*, 735-743.

Kennedy A. (1983). On Looking into Space. In: Rayner K, editor. *Eye Movements in Reading: Perceptual and Language Processes.* New York: Academic Press; pp. 237–251.

Kennedy, A. (1995). The influence of parafoveal words on foveal inspection time. *Paper presented at AMLaP-95 Conference, Edinburgh, UK.*

Kennedy, A. (1998). The influence of parafoveal words on foveal inspection time: Evidence for a processing trade-off. In G.Underwood (Ed.), *Eye guidance in reading and scene perception* (pp.149-223). Oxford: Elsevier.

Kennedy, A. (2000a). Attention allocation in reading. In A.Kennedy, R.Radach, D.Heller & J.Pynte (Eds.), *Reading as a perceptual process* (pp.193-220). Oxford: Elsevier.

Kennedy, A. (2000b). Parafoveal processing in word recognition, *Quarterly Journal of Experimental Psychology, 53A*, 429-455.

Kennedy, A. (2003). On keeping word order straight. Commentary on Reichle, E.D., Rayner, K., & Pollatsek, A. The E-Z Reader model of eye- movement control in reading: Comparison to other models. *Brain and Behavioral Sciences, 26,* 445-476.

Kennedy, A., Hill, R., & Pynte, J. (2003). *The Dundee Corpus* (Conference Paper). Proceedings of the 12th European conference on eye movements.

Kennedy, A. & Murray, W.S. (1987a). The components of reading time. In J.K. O'Regan & A. Levy-Schoen (Eds.). *Eye Movements: From Physiology to Cognition*. Amsterdam: Elsevier.

Kennedy, A. & Murray, W.S. (1987b). Spatial coordinates and reading: Comments on Monk (1985). *Quarterly Journal of Experimental Psychology*, 39A, 649-656.

Kennedy, A., Murray, W.S., & Boissiere, C. (2004). Parafoveal pragmatics revisited. European Journal of Cognitive Psychology, 16, 128-153.

Kennedy, A., Murray, W.S., Jennings, F. & Reid, C. (1989). Comments on the generality of the principle of minimal attachment. *Language and Cognitive Processes. Special Issue on Parsing and Interpretation*, 4, 51-76.

Kennedy, A., & Pynte, J. (2005). Parafoveal-on-foveal effects in normal reading. *Vision Research,* 45, 153-168.

Kennedy, A., & Pynte, J. (2008). The consequences of violations to reading order: An eye movement analysis. *Vision Research, 48* (21), 2309-2320.

Kennedy, A., Pynte, J., & Ducrot, S. (2002). Parafoveal-on-foveal interactions in word recognition. *The Quarterly Journal of Experimental Psychology, 55A*, 1307-1337.

Kennedy, A., Pynte, J., Murray, W.S. & Paul, S-A.S. (Submitted). Frequency and Predictability effects in the Dundee Corpus: An eye movement analysis. *Journal of Experimental Psychology: Human Perception and Performance.*

Kennison, S.M., & Clifton, C. (1995). Determinants of parafoveal preview benefit in high and low working memory capacity readers: Implications for eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 68-81.

Kliegl, R. (2007). Towards a perceptual-span theory of distributed processing in reading: A reply to Rayner, Pollatsek, Drieghe, Slattery, & Reichle (2007). *Journal of Experimental Psychology: General*, *138*, 530-537.

Kliegl, R., & Engbert, R. (2003). SWIFT explorations. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 391-411). Amsterdam: Elsevier Science.

Kliegl, R., Grabner, E., Rolfs, M., & Engbert, R. (2004). Length, frequency, and predictability effects of words on eye movements in reading. *European Journal of Cognitive Psychology, 16*, 262-284.

Kliegl, R., Nuthmann, A. & Engbert, R. (2006). Tracking the mind during reading: the influence of past, present and future words on fixation durations. *Journal of Experimental Psychology, 135*, 12-35.

Kliegl, R., Risse, S., & Laubrock, J. (2007). Preview benefit and parafoveal-on-foveal effects from word n+2. *Journal of Experimental Psychology: Human Perception and Performance, 33 (5), 1250-1255.*

Kolers, P.A. (1976). Buswell's discoveries. In R.A. Monty & J.W. Senders (Eds.), *Eye movements and psychological processes.* Hillsdale, NJ: Erlbaum.

Konieczny, L. (1996). Human Sentence Processing: A Semantics Oriented Parsing Approach. *Unpublished doctoral dissertation, University of Freiburg.*

Konieczny, L., & Hemforth, B. (2000). Modifier attachment in German: relative clauses and prepositional phrases. In A. Kennedy & J. Pynte (Eds.) *Reading as a Perceptual Process:* Elsevier.

Kowler, E., & Anton, S. (1987). Reading twisted text: Implications for the role of saccades. *Vision research*, *27,* 45-60.

Kuçera, H., & Francis, W.N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Kutas, M. & Hillyard, S.A. (1980). Reading senseless sentences: brain potentials reflect semantic incongruity. *Science, 207,* 203-204.

Lavigne, F., Vitu, F., & d'Ydewalle, G. (2000). The influence of semantic context on initial landing sites in words. *Acta Psychologica*, *104*, 191-214.

Levin, H., & Kaplan, E.L. (1970). Grammatical structure and reading. In H.Levin & J. Williams (Eds.), Basic studies in reading. New York: Basic Books.

Levy, R. (2008). Expectation-based syntactic comprehension. *Cognition, 106*, 1126-1177).

Liversedge, S.P., Paterson, K.B., & Pickering, M.J. (1998). Eye Movements and Measures of Reading Time. In G. Underwood (Ed.), *Eye Guidance in Reading and Scene Perception.* Oxford: Elsevier.

Liversedge, S.P., & White, S.J. (2003). Psycholinguistic processes affect fixation durations and orthographic information affects fixation locations: Can E-Z Reader cope? *Behavioural and Brain Sciences, 26,* 492-493.

Luce, R. D. (1959). *Individual Choice Behavior: A Theoretical Analysis*. New York: Wiley.

Matin, E. (1974). Saccadic suppression: A review. *Psychological Bulletin, 81*, 899-917.

McCann, R.S., & Besner, D. (1987). Reading pseudohomophones: Implications for models of pronunciation assembly and the locus of word frequency effects in naming. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 14-24.

McClelland, J.L. (1987). The case for interactionism in language processing. In M.Coltheart (Ed.), *Attention and performance XII: The Psychology of reading* (pp.3-36). Hillsdale, NJ: Erlbaum.

McClelland, J. L., & O'Regan, J. K. (1981). On visual and contextual factors in reading: A reply to Rayner and Slowiaczek. *Journal of Experimental Psychology: Human Perception and Performance, 7*, 652-657.

McConkie, G.W., Kerr, P.W., Reddix, M.D., & Zola, D. (1988). Eye movement control during reading: I. The location of initial eye fixations in words. *Vision Research, 28*, 1107-1118.

McConkie, G.W., Kerr, P.W., Reddix, M.D., Zola, D., & Jacobs, A.M. (1989). Eye movement control during reading: II.Frequency of refixating a word. *Perception & Psychophysics, 46*, 245-253.

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception & Psychophysics, 17*, 578-586.

McCullough, C. (2001). Eye movements and lexical access: The nature of the frequency and length effects. (*Unpublished dissertation thesis*).

McCusker, L.M. (1977, April). *Some determinants of word recognition: Frequency*. Paper presented at the 24th Annual Convention of the Southwestern Psychological Association, Fort Worth, TX.

McDonald, S.A. & Shillcock, R.C. (2003a). Eye movements reveal the on-line computation of lexical probabilities during reading. *Psychological Science, 14*, 648-652.

McDonald, S.A. & Shillcock, R.C. (2003b). Low-level predictive inference in reading: The influence of transitional probabilities on eye movements. *Vision Research, 43*, 1735-1751.

Mitchell, D.C., Brysbaert, M., Grondelaers, S., & Swanepoel, P. (2000). Modifier attachment in Dutch: Testing aspects of construal theory. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process*, (pp. 493-

516. Oxford: Elsevier.

Monsell, S., Doyle, M.C., & Haggard, P.N. (1989). Effects of frequency on word recognition tasks: Where are they? *Journal of Experimental Psychology: General,* 118, 43-71.

Morris, R.K. (1994). Lexical and Message-Level Sentence Context Effects on Fixation Times in Reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 92-103.

Morris, R. K., Rayner, K., & Pollatsek, A. (1990). Eye movement guidance in reading: The role of parafoveal letter and space information. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 268-281.

Morrison, R.E. (1984). Manipulation of stimulus onset delay in reading: Evidence for parallel programming of saccades. *Journal of Experimental Psychology: Human Perception and Performance*, *10,* 667-682.

Morton, J. (1969). Interaction of information in word recognition. *Psychological Review, 76,* 165-178.

Mouchetant-Rostaing, Y., Giard, M.-H., Bentin, S., Aguera, P.-E., & Pernier, J. (2000). Neurophysiological correlates of face gender processing in humans. *European Journal of Neuroscience, 12,* 303-310.

Murray, W.S. (1998). Parafoveal pragmatics. In G. Underwood (Ed.)*, Eye guidance in reading and scene perception* (pp.181-200). Oxford, England: Elsevier.

Murray, W.S. (2005). The Nature and Time Course of Pragmatic Plausibility Effects. *Journal of Psycholinguistic Research (Special Issue), 35(1),* 79-99.

Murray, W.S. (2000). Sentence processing: Issues and measures. In A. Kennedy, R. Radach, D. Heller & J. Pynte (Eds). *Reading as a Perceptual Process*. (pp. 649-664) Oxford: Elsevier.

Murray, W.S. & Kennedy, A. (1988). Spatial coding in the processing of anaphor by good and poor readers: Evidence from eye movement analyses. *Quarterly Journal of Experimental Psychology,* 40A, 693- 718.

Murray, W.S., & Liversedge, S.P. (1994). Referential context effects on syntactic processing. In C. Clifton, Jr., L. Frazier, and K. Rayner (Eds.), *Perspectives on Sentence Processing*. Hillsdale, N.J: Erlbaum.

Murray, W.S., & Rowan, M. (1998). Early, mandatory, pragmatic processing. *Journal of Psycholinguistic Research, 27,* 1-22.

Ni, W., Crain, S., & Shankweiler, D. (1996). Sidestepping garden paths: the contribution of syntax, semantics and plausibility in resolving ambiguities. *Language and Cognitive Processes, 11,* 283-334.

Norris, D. (1984). The effects of frequency, repetition, and stimulus quality in visual word recognition. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 36 (A), 507-515.

Nuthmann, A., Engbert, R., & Kliegl, R. (2005). Mislocated fixations during reading and the inverted optimal viewing position effect. *Vision Research, 45*, 2201-2217.

Ong, J. K. Y. & Kliegl, R. (2008). Conditional co-occurrence probability acts like frequency in predicting fixation durations. *Journal of Eye Movement Research, 2(1):3*, 1-7.

O'Regan, J.K. (1990). Eye movements and reading. In E.Kowler (Ed.), *Eye movements and their role in visual and cognitive processes* (pp. 395-453). Amsterdam: Elsevier.

O'Regan, J.K. (1992). Optimal viewing position in words and the strategy-tactics theory of eye movements in reading. In K.Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading* (pp.333-354). New York: Springer-

Verlag.

O'Regan, J.K., & Lévy-Schoen, A. (1987). Eye movement strategy and tactics in word recognition and reading. In M Coltheart (Ed.), *Attention and performance: Vol, 12. The psychology of reading* (pp.363-383). Hillsdale, NJ: Erlbaum.

Paap, K.R., Mcdonald, J.E., Schvaneveldt, R.W., & Noel, R.W. (1987). Frequency and pronounceability in visually presented naming and lexical decision tasks. In M.Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 221-243). Hillsdale, NJ: Erlbaum.

Patson, N.D. & Warren, T. (2010). Eye movements when reading implausible sentences: Investigating potential structural influences on semantic integration. *Quarterly Journal of Experimental Psychology, 63(8),* 1516-1532.

Perea, M., & Pollatsek, A. (1998). The effects of neighborhood frequency in reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 767-777.

Pollatsek, A., Lesch, M., Morris, R. K., & Rayner, K. (1992). Phonological codes are used in integrating information across saccades in word identification and reading. *Journal of Experimental Psychology*: Human Perception and Performance, 18, 148-162.

Pollatsek, A., & Rayner, K. (1990). Eye movements and lexical access in reading. In D.A. Balota, G.B. Flores d' Arcais, & K. Rayner (Eds.), *Comprehension processes in reading* (pp.143-164). Hillsdale, NJ: Erlbaum.

Pollatsek, A., Rayner, K., & Balota, D.A. (1986). Inferences about eye movement control from the perceptual span in reading. *Perception & Psychophysics, 1986, 40,* 123-130.

Pollatsek, A., Reichle, E., & Rayner, K. (2006c). Tests of the E-Z Reader model:

Exploring the interface between cognition and eye-movement control. *Cognitive Psychology, 52*, 1-56.

Pynte, J. & Kennedy, A. (2005). Cross-linguistic differences in the Dundee Corpus (Conference Paper). *Proceedings of the 13th European conference on eye movements.*

Pynte, J., & Kennedy, A. (2006). An influence over eye movements in reading exerted from beyond the level of the word: Evidence from reading English and French. *Vision Research, 46,* 3786-3801.

Pynte, J., Kennedy, A., & Ducrot, S. (2004). The influence of parafoveal typographical errors on eye movements in reading. *European Journal of Cognitive Psychology, 16 (1/2)*, 178-202.

Pynte, J., Kennedy, A., Murray ; W.S., Courrieu, P. (1988). The effect of spatialisation on the processing of ambiguous pronominal reference. In G. Lüer and U. Lass, J. Shallo-Hoffmann (Eds.), Eye Movement Research: Physiological and Psychological Aspects. Göttingen: Hogrefe.

Pynte, J., New, B. and Kennedy A. (2008). On-line contextual influences during reading normal text: a multiple-regression analysis. *Vision Research, 48,* 2172-2183.

R Development Core Team (2006). *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria.

Radach, R., & Glover, L. M. (2007). *Exploring the limits of spatially distributed word processing in normal reading: A new look at n + 2 preview effects.* Paper presented at the European Conference on Eye Movements, Potsdam, Germany, August.

Radach, R., & Heller, D. (2000). Relations between spatial and temporal aspects of eye movement control. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process*. (pp.165-191). Oxford, UK: Elsevier.

Radach, R., Inhoff, A., & Heller, D. (2004). Orthographic regularity gradually modulates saccade amplitudes in reading. *European Journal of Cognitive Psychology, 16* (1/2), 27-51.

Radach, R., & Kempe, V. (1993). An individual analysis of initial fixation positions in reading. In G. d'Ydewalle & J.Van Rensbergen (Eds.), *Perception and cognition: Advances in eye movement research* (pp.213-226). Amsterdam: North Holland.

Radach, R., & McConkie, G.W. (1998). Determinants of fixation positions in words during reading. In G. Underwood (Ed.), *Eye Guidance in Reading and Scene Perception* (pp. 77 – 100). Amsterdam: Elsevier.

Raney, G.E., & Rayner, K. (1995). Word frequency effects and eye movements during readings of a text. *Canadian Journal of Experimental Psychology, 49,* 151-172.

Rayner, K. (1975b). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7,* 65-81.

Rayner, K. (1977). Visual attention in reading: Eye movements reflect cognitive processes. *Memory & Cognition, 4,* 443-448.

Rayner, K. (1979). Eye guidance in reading: Fixation locations in words. *Perception, 1979, 8,* 21 – 30.

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *Journal of Experimental Child Psychology, 41,* 211-236.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372-422.

Rayner, K., Ashby, J., Pollatsek, A., & Reichle, E.D. (2004). The effects of frequency and predictability on eye fixations in reading: Implications for the E-Z Reader model. *Journal of Experimental Psychology: Human Perception and Performance*, 3*0*, 720- 732.

Rayner, K., & Bertera, J. H. (1979). Reading without a fovea. *Science, 206,* 468-469.

Rayner, K., Binder, K.S., Ashby, J., & Pollatsek, A. (2001). Eye movement control in reading: word predictability has little influence on initial landing positions in words. *Vision Research*, *41*, (7), 943-954.

Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing: Eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning and Verbal Behavior, 22,* 358-374.

Rayner, K., & Duffy, S.A. (1986). Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition, 14*, 191-201.

Rayner K., & Fischer, M.H. (1996). Mindless reading revisited: Eye movements during reading and scanning are different. *Perception & Psychophysics*, *58*, 734-747.

Rayner, K., Fischer, M.H., & Pollatsek, A. (1998). Unspaced text interferes with both word identification and eye movement control. *Vision Rese*arch, *38*, 1129-1144.

Rayner, K., Juhasz, B.J., & Brown, S.J. (2007). Do readers obtain preview benefit from word n + 2? A test of serial attention shift versus distributed lexical processing models of eye movement control in reading. *Journal of Experimental Psychology: Human Perception and Performance, 33,* 230 – 245.

Rayner, K., Kambe, G., & Duffy, S.A. (2006). Clause wrap-up effects on eye movements during reading. *Quarterly Journal of Experimental Psychology, 53,* 1061-1080.

Rayner, K., Li, X., Juhasz, B.J., & Yan, G. (2005). The effect of predictability on the eye movements of Chinese readers. *Psychonomic Bulletin & Review, 12*, 1089-1093.

Rayner, K., & McConkie, G. W. (1976). What guides a reader's eye movements. *Vision Research*, *16*, 829-837.

Rayner, K., & Pollatsek, A. (1987). Eye movements in reading: A tutorial review. In M.Coltheart (Ed.), Attention and performance (Vol. 12, pp. 327-362). London: Erlbaum.

Rayner, K., & Pollatsek, A. (1989). *The psychology of reading*. Englewood Cliffs, NJ: Prentice Hall.

Rayner, K., & Raney, G.E. (1996). Eye movement control in reading and visual research: Effects of word frequency. *Psychonomic Bulletin & Review*, 3, 238-244.

Rayner, K., Raney, G.E., & Pollatsek, A. (1995). Eye movements and discourse processing. In R.F. Lorch & E.J. O'Brien (Eds.) *Sources of coherence in reading* (pp. 9-36). Hillsdale, NJ: Erlbaum.

Rayner, K., Reichle, E.D., & Pollatsek, A. (2005). Eye movement control in reading and the E-Z Reader model. In G. Underwood (Ed.), *Cognitive processes in eye guidance*. Oxford: Oxford University Press.

Rayner, K., Sereno, S.C., & Raney, G.E. (1996). Eye movement control in reading: A comparison of two types of models. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 1188-1200.

Rayner, K., Slowiaczek, M.L., Clifton, C., & Bertera, J.H. (1983). Latency of sequential eye movements: Implications for reading. *Journal of Experimental Psychology, Human Perception and Performance, 9*, 912-922.

Rayner, K., Warren, T., Juhasz, B.J., & Liversedge, S.P. (2004). The effect of plausibility on eye movements in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 1290-1301.

Rayner, K., & Well, A.D. (1996). Effects of contextual constraint on eye movements in reading: A further examination. *Psychonomic Bulletin & Review, 3*, 504-509.

Rayner, K., Well, A. D., Pollatsek, A., & Bertera, J. H. (1982). The availability of useful information to the right of fixation in reading. *Perception & Psychophysics*, 31, 537-550.

Rayner, K., White, S.J., Kambe, G., Miller, B., & Liversedge, S.P. (2003). On the processing of meaning from parafoveal vision during eye fixations in reading. In J. Hyona, R.Radach, & H.Deubel (Eds), *The mind's eye: Cognitive and applied aspects of eye movements.* Oxford:Elsevier.

Reichle, E.D., McConnell, K., & Warren, T. (2009). Using E-Z Reader to Model the Effects of Higher-Level Language Processing on Eye Movements During Reading. *Psychonomic Bulletin & Review, 16 (1),* 1 -21.

Reichle, E.D., Pollatsek, A., Fisher, D.L., & Rayner, K. (1998). Towards a model of eye movement control in reading. *Psychological Review, 105,* 125-157.

Reichle, E.D., Pollatsek, A., & Rayner, K. (2006). *E-Z* Reader: A cognitive-control, serial-attention model of eye-movement behaviour during reading. *Cognitive Systems Research, 7,* 4 – 22.

Reichle, E.D., Rayner, K., & Pollatsek, A. (2003). The E-Z Reader model of eye-movement control in reading: Comparison to other models. *Brain and Behavioral Sciences, 26,* 445-476.

Reilly, R.G. & O'Regan, J.K. (1998). Eye movement control during reading: A simulation of some word-targetting strategies. *Vision Research, 38,* 303-317.

Reilly, R.G., & Radach, R. (2003). Foundations of an interactive model of eye Movement control in reading. In Hyona, J., Radach, R., & Deubel, H. (Ed.), *Cognitive and Applied Aspects of Eye Movement Research*. Amsterdam: Elsevier, pp. 429-455.

Richter, E.M., Engbert, R., & Kligl, R. (2006). Current advances in SWIFT. *Cognitive Systems Research, 7,* 23-33.

Scarborough, D.L., Cortese, C., & Scarborough, H. (1977). Frequency and repetition effects in lexical memory. Journal of Experimental Psychology: *Human Perception and Performance*, *7,* 3-12.

Schilling, H.E.H., Rayner, K., & Chumbley, J.I. (1998). Comparing naming, lexical decision, and eye fixation times: Word frequency effects and individual differences. *Memory & Cognition, 26,* 1270-1281.

Schroyens, W., Vitu, F., Brysbaert, M., & d'Ydewalle, G. (1999). Visual attention and eye-movement control during reading: The case of parafoveal processing. *Quarterly Journal of Experimental Psychology*, *52A*, 1021-1046.

Schustack, M.W., Ehrlich, S.F., & Rayner, K. (1987). The complexity of contextual facilitation in reading: Local and global influences. *Journal of Memory and Language*, *26,* 322-340.

Sereno, S.C., Brewer, C.C., & O'Donnell, P.J. (2003). Context effects in word recognition: Evidence for early interactive processing. *Psychological Science,* 14, 328-333.

Sereno, S.C., & Rayner, K. (2000). The when and where of reading in the brain. *Brain and Language, 2000, 42,* 78-81.

Smith, F. (1971). *Understanding reading*. New York: Holt, Rinehart & Winston.

Sparrow, L., Miellet, S. & Coello, Y. (2003). The effects of frequency and predictability on eye fixations in reading: An evaluation of the E-Z Reader model. In Reichle, E.D., Rayner, K., & Pollatsek, A. The E-Z Reader model of eye movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences, 26,* 445-526.

Spivey, M. J. (2007). *The continuity of mind.* New York: Oxford University Press.

Stanners, R.F., Jastrzembski, J.E., & Westbrook, A. (1975). Frequency and visual quality in a nonword classification task. *Journal of Verbal Learning and Verbal Behavior, 14*, 259-264.

Stanovich, K.E., & West, R.F. (1979). Mechanisms of sentence context effects in reading: Automatic activation and conscious attention. *Memory & Cognition, 7,* 77-85.

Stanovich, K.E., & West, R.F. (1983). The generalizability of context effects on word recognition: A reconsideration of the roles of parafoveal priming and sentence context. *Memory & Cognition, 11,* 49-58.

Starr, M.S., & Inhoff, A.W. (2004). Attention allocation to the right and left of a fixated word: Use of orthographic information from multiple words during reading. *European Journal of Cognitive Psychology, 16,* 203-225.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. Acta Psychologica, 30, 276-315.

Taylor,W. L. (1953). Cloze Procedure: a new tool for measuring readability. *Journalism Quarterly, 30,* 415–433.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994) Semantic Influences on Parsing: The use of thematic role information in syntactic ambiguity resolution. *Journal of Memory and Language, 33,* 285-318.

Underwood, G., Binns, A., & Walker, S. (2000). Attentional demands on the processing of neighbouring words. In A.Kennedy, R.Radach, D.Heller & J.Pynte (Eds.), *Reading as a perceptual process* (pp.247-268). Oxford: Elsevier.

Vainio, S., Hyönä, J., & Pajunen, A. (2009). Lexical predictability exerts robust effects on fixation duration, but not on initial landing position during reading. *Experimental Psychology, 56,* 66-74.

Van Berkum, J.J.A., Brown, C.M., Zwitserlood, P., Kooijman, V., & Hagoort, P. (2005). Anticipating Upcoming Words in Discourse: Evidence from ERPs and Reading Times. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31 (3),* 443-467.

Van Gompel, R.P.G., Pickering, M.J., & Traxler, M.J. (2000). Unrestricted race: A new model of syntactic ambiguity resolution. In: A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process*. Oxford: Elsevier.

Van Rullen, R., & Thorpe, S. (2001). The time course of visual processing: From early perception to decision-making. *Journal of Cognitive Neuroscience, 13,* 454-461.

Vitu, F. (1991). The influence of parafoveal processing and linguistic context on the optimal landing position effect. *Perception & Psychophysics, 50*, 58-75.

Vitu, F. (1991*b*). Against the existence of a range effect in reading. *Vision Research, 31 (11),* 2009-2015.

Vitu, F., Lancelin, D., & Marrier d'Unienville, V. (2007). A Perceptual-Economy Account for the Inverted-Optimal Viewing Position Effect. *Journal of Experimental Psychology: Human Perception and Performance, 33 (5),* 1220-1249.

Vitu, F., McConkie, G.W., Kerr, P., & O'Regan, J.K. (2001). Fixation location effects on fixation durations during reading: An inverted optimal viewing position effect.

Vision Research, 41, 3513-3533.

Vonk, W., Radach, R., & Van Rijn, H. (2000). Eye guidance and the saliency of word beginnings in reading text. In A. Kennedy, R. Radach, D. Heller & J. Pynte (Eds.), *Reading as a perceptual process* (pp.269-299). Oxford: Elsevier.

Wang, C-A., Inhoff, A.W., & Radach, R. (2009). Is attention confined to one word at a time? The spatial distribution of parafoveal preview benefits during reading. *Attention, Perception & Psychophysics, 71,* 1487-1494.

Warren, T. & McConnell, K. (2007). Investigating effects of selectional restriction violations and plausibility violation severity on eye-movements in reading. *Psychonomic Bulletin & Review, 14(4),* 770-775.

West, R. F. & Stanovich, K. E. (1982). The source of inhibition in experiments on the effects of sentence context on word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 385–399.

Whaley, C.P. (1978). Word-non-word classification time. *Journal of Verbal Learning and Verbal Behavior*, *17*, 143-154.

White, S.J., & Liversedge, S.P. (2004). Orthographic familiarity influences initial eye fixation positions in reading. *European Journal of Cognitive Psychology, 16,* 52-78.

Wurtz, R.H. (1996). Vision for the control of movement. *Investigative Ophthalmology and Visual Science, 37,* 2173-2175.

Yang, S. N., & McConkie, G. W. (2001). Eye movements during reading: A theory of saccade initiation times. *Vision Research, 41*, 3567-3585.

Yang, S.-N., & McConkie, G. W. (2004) Saccade generation during reading: Are words necessary? *European Journal of Cognitive Psychology, 16,* 226 - 261.

Zola, D. (1984). Redundancy and word perception during reading. *Perception &*

Psychophysics, 36, 277-284.

APPENDIX A

Experimental sentence frames, target-previews and target words employed in Eye-tracking Experiments 1 and 2:

List 1

The target-previews are italicized and separated by slashes in the following order:

Identical High-Frequency Predictable/

Misspelled High-Frequency Predictable/

Visually Dissimilar Misspelled High-Frequency Predictable/

Identical Low-Frequency Unpredictable/

Misspelled Low-Frequency Unpredictable/

Visually Dissimilar Misspelled Low-Frequency Unpredictable

The target words are under-lined and separated by slashes in the following order:

High-Frequency Predictable/

Low-Frequency Unpredictable

1. Both of the boys had black eyes and sore knuckles after having a huge *fight/ frpbt/ oetgc/ brawl/ biezl/ cosla* fight/brawl earlier in the week.

2. Most cowboys know how to ride a fine *horse/ hcnze/ ehicu/ camel/ cewal/ tteco* horse/camel if necessary.

3. Wondering if it was lunchtime, Jason checked the time on the new gold *watch/ woleh/ edahu/ clock/ ctcak/ eomre* watch/clock he got for Christmas.

4. The lovely wedding cake was cut using a long silver *knife/ kreqe/ nfyrl/ spoon/ sgccn/ tsmfo* knife/spoon so that everyone could have a piece.

5. The teacher kept the class quiet while she read a short *story/ slciy/ ratim/ diary/ droiy/ alhce* story/diary at the end of the day.

6. Wanting to live together, the couple moved into their first *house*/ *hcaze*/ *dwlrf/ igloo/ iptco/ leacf* house/igloo and were excited.

7. Joey's mother was horrified by the slithering fierce *snake/ saote/ lnkel/ shark/ sboik/ iohnr* snake/shark even though it was very small.

8. After listening to the jury, the sentence was passed by the clever *judge/ jabpe/ cioof/ actor/ aelar/ hsiga* judge/actor and the case was closed.

9.The students listened to a lecture given by the nutty *professor/ picqessor/ ihlporsch/ policeman/ patrceman/ nakeohpyl* professor/policeman in the lecture theatre.

10. The secretary put up a funny poster on the door of her small *office/ oqqrce/* kjuenf*/ locker/ laeher/ odsmie* office/locker for everyone to see.

11. The bride walked slowly down the aisle of the small *church/ cboich/ bseerf castle/ cozkle/ otohak* church/castle whilst holding a bouquet of flowers.

12. After strutting on the catwalk, the lovely *model/ mcbol/ edgso/ boxer/ bawcr/ ruorc* model/boxer sat down to rest.

13. After partaking in both the tap and ballet competitions, the talented young *dancer/ deceer/ cafsrl/ golfer/ gatqer/ cbrrso* dancer/golfer won a medal.

14. After emptying the bucket, the lady mopped the dirty *floor/ ftccr/ sksrt/ shelf/ sbctf/ lioos* floor/shelf in the kitchen.

15. The dentist wiped Mary's sore *mouth/ mcnlh/ onrce/ cheek/cbcck/ togac* mouth/cheek before letting her go home.

16. After finishing another spectacular portrait, the fine *artist/ ailrst/ xgrwre/ singer/ srmper/ ekehpa* artist/singer drank lots of wine.

List 2

The target-previews are italicized and separated by slashes in the following order:

Identical Low-Frequency Predictable/

Misspelled Low-Frequency Predictable/

Visually Dissimilar Misspelled Low-Frequency Predictable/

Identical High-Frequency Unpredictable/

Misspelled High-Frequency Unpredictable/

Visually Dissimilar Misspelled High-Frequency Unpredictable

The target words are under-lined and separated by slashes in the following order:

Low-Frequency Predictable/

High-Frequency Unpredictable

1. The landlord had to close the pub as there had been a bar room *brawl/ biezl/ cosla/ fight/ frpbt/ oetgc* brawl/fight which had caused much damage.

2. In the desert, many Arabs ride a fine *camel/ cewal/ tteco/ horse/ hcnze/ ehicu* camel/horse to get around.

3. Fred looked over at the mantelpiece to check the time on the gold *clock/ ctcak/ eomre/ watch/ woleh/ edahu* clock/watch he got from his friend.

4. The little girl ate jelly and ice-cream with a small silver *spoon/ sgccn/ tsmfo/ knife/ kreqe/ nfyrl* spoon/knife after eating her dinner.

5. After writing down her secret thoughts, Sally hid her small *diary/ droiy/ alhce/ story/ slciy/ ratim* diary/story in the closet.

6. Using snow and ice, the Eskimo family built their first *igloo/ iptco/ leacf/ house/ hcaze/ dwlrf* igloo/house at the North Pole.

7. The man was in dangerous waters when attacked by the fierce *shark/ sboik/ iohnr/ snake/ saote/ lnkel* shark/snake that almost killed him.

8. Although he had played a leading part in a police movie the clever *actor/ aelar/ hsiga/ judge/ jabpe/ cioof* actor/judge wanted a better job.

9. After he had disarmed two criminals and handcuffed them, the brave *policeman/ patrceman/ nakeohpyl/ professor/ picqessor/ ihlporsch/* policeman/professor sat down to rest.

10. At work, Andrew kept his valuables and gym clothes in his small *locker/ laeher/ odsmie/ office/ oqqrce/ kjuenf* locker/office to keep them safe.

11. The knight kept his swords hidden in a secret room of the grand *castle/ cozkle/ otohak/ church/ cboich/ bseerf* castle/church so no-one could find them.

12. After knocking out his opponent, the feisty *boxer/ bawcr/ ruorc/ model/ mcbol/ edgso* boxer/model went to get changed.

13. After hitting a hole in one the talented young golfer/ gatqer/ *cbrrso*/ dancer/ deceer/ *cafsrl* golfer/dancer received a standing ovation from the crowd.

14. The boy stacked his books neatly on the dusty *shelf/ sbctf/ lioos/ floor/ ftccr/ sksrt* shelf/floor in the bedroom.

15. Susan kissed her friend's rosy *cheek/ cbcck/ togac/ mouth/ mcnlh/ onrce* cheek/mouth when they were finally re-united.

16. The vocal coach knew the young girl would be a fine *singer/ srmper/ ekehpa/ artist/ ailrst/ xgrwre* singer/artist when she grew up.

APPENDIX B

Instructions for the cloze task employed in Experiments 1 and 2 (as well as an example sentence fragment):

Please continue the sentence with the first word that comes into your mind. It's important not to spend a lot of time thinking about it – just put the very first word you think appropriate. It should only take 5-10 minutes to complete all of the sentences.

1. Both of the boys had black eyes and sore knuckles after having a huge ___________

APPENDIX C

Instructions for plausibility ratings task employed in Experiments 1, 2, 3, 4, and 5:

In this short task, I would like you to rate each of the following sentences in terms of how "plausible" it is. By this I mean the ordinariness or likelihood of the event described by the phrase actually happening or being true. Thus a plausible sentence will describe a very ordinary event that has a high probability of occurring in everyday life, whereas an implausible sentence will describe a very bizarre or unexpected event that is not very likely to occur. The more plausible you think the sentence is, the higher the plausibility rating you should give it.

For example, the sentence:

The schoolboys discussed the scary film they saw at the cinema last week.

Is quite plausible, whereas:

The mouse criticised the blue flowers as they flew high in the sky.

Is quite implausible.

Your task is to read each of the sentences and give it a rating on a seven point scale of plausibility on which a score of 7 corresponds to a highly plausible sentence, while a score of 1 should be given to a highly implausible sentence, with the other scores representing gradings on the scale at even intervals in between.

1 2 3 4 5 6 7

For each sentence you should assign it a number corresponding to your estimate of its plausibility. Do this by circling the appropriate number on the scale below the sentence.

APPENDIX D

Participant information sheet for Eye-tracking Experiments 1 and 2:

PARTICIPANT INFORMATION SHEET

The role of word-frequency and predictability effects in eye movement control during reading.

You are being asked to take part in an eye movement experiment which is being carried out as part of my PhD. The research is being supervised by Professor Alan Kennedy and Dr. Wayne Murray, both of this psychology department.

The study is an investigation into how high- and low-frequency predictable and unpredictable words are processed during normal reading. This will be investigated by tracking your eye movements as you read sentences on a computer screen. This research is beneficial to those in the field of eye movement control in reading.

You participation in this study is voluntary and will take approximately 30 minutes of your time. The task is not at all stressful and there are no known risks for you in this study however you may decide to discontinue the experiment at any time without explanation. In return for your participation you will receive course credit or a payment of £3.

The data we collect do not contain any personal information about you and no-one will link the data you provided to your identity and name.

The instructions for the experiment are as follows:

When this experiment begins, it will first be necessary to calibrate the eye tracker. Therefore, the first thing you will see will be a set of ‘calibration markers’. These are numbers on the screen which you will be asked to look at in turn. You should simply follow my instructions at this point.

Following the calibration procedure you will be asked to read a number of sentences presented on the screen in front of you. First, a fixation mark will appear on the screen. When you look at this, a sentence will be displayed. When you have finished reading the sentence, press the button on your right-hand side. The words ‘Press button’ will then appear on the screen and you should press the right-hand button again. Occasionally following a sentence a question will be displayed instead of the ‘Press button’ instruction. Answer the question by pressing either the right-hand button for “yes” or the left-hand button for “no” responses.

The procedure is thus:

- A fixation mark appears on the screen
- Look at the fixation mark
- A sentence appears on the display
- You read the sentence
- You press the right-hand button
- The ‘Press button’ instruction will appear on the screen
- You press the right-hand button
- On some occasions instead of the ‘Press button’ instruction, a question will follow the sentence
- You answer the question using the right button for ‘yes’ and the left for ‘no’
- A fixation mark appears. And so on…

If you get an answer wrong, you will hear a buzzer, but please note that this experiment is not a test of your reading ability or your intelligence. You will be given plenty of practice, providing an opportunity to familiarise yourself with the task.

Every now and then it will be necessary to re-calibrate the eye tracker. Re-calibration will be similar to the calibration procedure carried out at the beginning of the experiment. Simply follow my instructions when we reach this point.

It is very important that you keep you head **absolutely still** while the data are being collected. In particular, do not try to speak, even if you happen to get a question wrong. If you need to take a short break, the best time to do this is just before the calibration procedure. I will give you a rest break now and then, in any case.

If you have any questions or queries please raise them now. I will be glad to answer any questions about this study at any time, you can contact me by e-mail at S.S.Paul@dundee.ac.uk.

Shirley Paul, PhD student
Psychology Department
University of Dundee
DD1 4HN

The University Non-Clinical Research Ethics Committee of the University of Dundee has reviewed and approved this research study.

APPENDIX E

Experimental sentence frames and target words employed in Eye-tracking Experiments 3 and 4 (only the first 32 sentence frames were employed in Experiment 3). The target words are under-lined and a, b, c and d refer to high, moderately-high, low-predictable and unpredictable sentence frames respectively:

1a. At the river, Karen heard quacking and saw a pair of cute brown ducks swimming along together.
1b. The girls noticed some beautiful swans and a pair of cute brown ducks swimming along together.
1c. While walking past the river, Amy saw a pair of cute brown ducks swimming along together.
1d. While taking in the views, the girls noticed a pair of cute brown ducks swimming along together.

2a. Although scared of being eaten alive, the diver swam by lots of giant sharks and was intrigued.
2b. He knew they were dangerous, but the diver swam by lots of giant sharks and was intrigued.
2c. In the warm Australian waters, the young diver saw lots of giant sharks and was intrigued.
2d. While on an exotic holiday with his wife, Gordon saw lots of giant sharks and was intrigued.

3a. In the children's story, the evil witch cast a lot of magic spells and everyone was afraid.
3b. While in her attic, Judy found a book full of magic spells and everyone was curious.
3c. The teenager attempted to carry out a lot of magic spells and everyone was curious.
3d. The elderly woman taught her grandson a lot of magic spells and everyone was curious.

4a. The girl bought her mother a bouquet of pink and purple flowers for her new vase.

4b. Paula was kind, she took her friend some pink and purple flowers for her bedside.

4c. Patricia bought most of the beautiful pink and purple flowers for her new vase.

4d. The young lady couldn't wait to buy pink and purple flowers for her new vase.

5a. In the garden, Jill fed carrots and lettuce to her fluffy brown rabbit before she went to school.
5b. The young teenager went outside to feed her fluffy brown rabbit before she went to school.
5c. Jill kept lots of animals, her favourite was her fluffy brown rabbit before she got a cat.
5d. At the zoo, Rachel's favourite animal was the fluffy brown rabbit before she saw the tigers.

6a. Evelyn spent hours reading the entries in her secret diary and then went to bed.

6b. Evelyn spent hours and hours looking for her secret diary and then went to bed.

6c. Evelyn would write for hours and hours in her secret diary and then go to bed.

6d. Karen hadn't told any of her friends about her secret diary and then they found out.

7a. Liz was cutting the hedges and watering the plants in the pretty garden behind her house.
7b. Catriona's friend could be seen watering the plants in the pretty garden behind her house.
7c. The elderly lady could be seen bird-watching in the pretty garden behind her house.
7d. Catriona painted an absolutely wonderful picture of the pretty garden behind her house.

8a. In the story, the princess was locked in a tower inside the stone castle so no-one could find her.
8b. A huge drawbridge was built at the entrance of the stone castle so no-one could enter. P
8c. The knight kept his swords hidden in a room inside the stone castle so no-one could find them.
8d. In the story, the children hid in a small room inside the stone castle so no-one could find them.

9a. At Halloween, Ian used a white sheet to dress up as a scary ghost and everyone laughed.
9b. At Halloween, Suzanne always liked to dress up as a scary ghost and everyone laughed. P
9c. In the movie, the group of teenagers were chased by a scary ghost and everyone was scared.
9d. In the art gallery, there was a wonderful painting of a scary ghost and everyone wanted it.

10a. Everyone laughed when the waitress dropped the dinner plates she had been carrying.
10b. Kimberley saw a set of cups which matched the dinner plates she had recently bought.
10c. Jenny served her friends a delicious meal on the dinner plates she had recently bought. P
10d. Jennifer's friend Rachel absolutely loved the dinner plates she had recently bought.

11a. The soldier had his breakfast and did up the laces on his shiny boots then was ready to go.
11b. The soldier put on his uniform and tied the laces on his shiny boots then was ready to go.
11c. Upon waking, the soldier had his breakfast and put on his shiny boots then was ready to go.
11d. William picked up his heavy back-pack and found his shiny boots then was ready to go.

12a. At the party, Alf thought that Rita was wearing a very pretty dress and looked lovely.
12b. It wasn't white, but the bride was still wearing a very pretty dress and looked lovely.
12c. Samantha's friend had spent a lot of money on a very pretty dress and looked lovely.
12d. Samantha accidentally spilled a glass of milk on a very pretty dress and looked embarrassed.

13a. They looked for sea-shells and built sand-castles on the sunny beach and were very happy.
13b. The young couple liked to walk bare-foot along the sunny beach and were very happy.
13c. The kids loved the summer as they got to play on the sunny beach and were very happy.
13d. The two artists painted some lovely pictures of the sunny beach and were very happy.

14a. After seeing the cheese and the trap, the cat saw the little furry mouse and caught it.
14b. After hearing lots of squeaking, the cat saw the little furry mouse and caught it.

14c. While playing in the garden, the young boy saw a little furry mouse and chased it.
14d. In the shop, Gail liked the cuddly toys, she saw a little furry mouse and wanted it.

15a. Caroline fed both her pets then groomed them using the round <u>brush</u> she had recently bought. P
15b. The hair-dresser cut Kim's hair then styled it using the round <u>brush</u> she had recently bought.
15c. Carol put on her clothes then tidied her hair using the round <u>brush</u> she had recently bought.
15d. The bad-tempered little girl hit her big brother with the round <u>brush</u> she had recently bought.

16a. At the recycling centre, Ian accidentally smashed the glass <u>bottle</u> and got into trouble.
16b. Little Jimmy drank all of the Irn-bru straight from the glass <u>bottle</u> and got into trouble.
16c. While pouring juice, Kim accidentally smashed the glass <u>bottle</u> and got into trouble.
16d. At lunch, Ian leaned over, accidentally smashed the glass <u>bottle</u> and got into trouble.

17a. Liz wrote the address on the envelope and stuck on the festive <u>stamp</u> before posting the card.
17b. Tracey sent her daughter to the Post Office to buy a festive <u>stamp</u> before posting the card.
17c. At the shop, Tracey bought a card, envelope and a festive <u>stamp</u> before posting her mail.
17d. At the local shop, Tracey bought pens, paper and a festive <u>stamp</u> before posting her letters.

18a. In the forest, there were people chopping down the dying <u>trees</u> and taking them away.
18b. In the far distance, people were chopping down the dying <u>trees</u> and taking them away.
18c. The rowdy teenagers could be seen breaking up the dying <u>trees</u> and taking them away.
18d. In the far distance, people were bringing down the dying <u>trees</u> and taking them away.

19a. At Halloween, Ryan's father carved a face into the large round <u>pumpkin</u> and it looked scary.
19b. At the Halloween party, Martin played with the large round <u>pumpkin</u> and it was fun.
19c. At Halloween, Ryan's mother made soup using the large round <u>pumpkin</u> and it was tasty.
19d. Martin's friend was absolutely terrified of the large round <u>pumpkin</u> and he began crying.

20a. Joseph looked at his wrist to check the time on the silver <u>watch</u> he got at Christmas.
20b. During his break, Joseph checked the time on the silver <u>watch</u> he got at Christmas.
20c. As it was too big, Joe got some links taken out of the silver <u>watch</u> he got at Christmas.
20d. He searched his whole house, but Joe didn't find the silver <u>watch</u> he got at Christmas.

21a. Victoria's friend thought that the best circus act was the funny <u>clown</u> in the baggy trousers.
21b. Sally had been practising juggling as she was playing the funny <u>clown</u> in the local circus.
21c. Sid needed to learn some jokes as he was playing the funny <u>clown</u> in the local circus.
21d. Victoria was absolutely desperate to look like the funny <u>clown</u> in the baggy trousers.

22a. After her shower, Rebecca dried herself using the clean <u>towel</u> from the rack.

22b. While cleaning the bathroom, the maid folded the clean <u>towel</u> from the rack.

22c. Unsure if it had been used, the maid picked up the clean <u>towel</u> from the rack.

22d. Rebecca's dog got muddy paw-prints all over the clean <u>towel</u> from the rack.

23a. The whistling noise in the kitchen came from the green <u>kettle</u> that everyone shared.
23b. Amanda made herself a cup of coffee using the green <u>kettle</u> that everyone shared.

23c. Amanda made herself a cup of soup using the green <u>kettle</u> that everyone shared.

23d. Amanda went shopping and bought herself the green <u>kettle</u> that everyone was looking at.

24a. At the office, David kept his juice cool in the mini silver <u>fridge</u> he got for his birthday.
24b. At the office, David kept his juice inside the mini silver <u>fridge</u> he got for his birthday.
24c. At the office, David kept his lunch inside the mini silver <u>fridge</u> he got for his birthday.
24d. Ted fixed the fan which had broken inside the mini silver <u>fridge</u> he got for his birthday.

25a. After listening to the boy's heart with the stethoscope, the junior doctor gave the bad news.
25b. After she had taken some blood and urine samples, the junior doctor gave the lady advice.
25c. After listening to all of the patient's problems, the junior doctor gave the bad news.
25d. After having a romantic dinner in a fancy restaurant, the junior doctor gave the lady flowers.

26a. At his friend's birthday party, Edward burst the giant balloon and then got upset.

26b. At the show, the entertainer made a dog out of the giant balloon and then burst it.

26c. At the party, the boy cried when he let go of the giant balloon and then felt silly.

26d. The little boy was fascinated when he saw the giant balloon and then the clown.

27a. The vocal coach knew the young girl would be a lovely singer when she grew up.

27b. Cassandra had a great musical career as she was a lovely singer when she tried.

27c. Cassandra made it into the pop band as she was a lovely singer when she tried.

27d. Everybody thought that young Cassandra was a lovely singer when she tried.

28a. After hitting a hole in one twice in a row, the amazing golfer won the game.

28b. His last ball initially went past the hole, but the amazing golfer won the game.

28c. The lucky tee seemed to work because the amazing golfer won the game.

28d. Even though he had drunk a lot of alcohol, the amazing golfer won the game.

29a. In the morning, Andy neatly tied the stripy tie on top of the brown shirt he wore to work.
29b. As Tim was attending an interview, he dried and ironed the brown shirt he wore to work.
29c. Tim looked for the pair of trousers which matched the brown shirt he wore to work.
29d. Craig looked everywhere in the house but couldn't find the brown shirt he wore to work.

30a. The couple travelled across the railway bridge in the packed train and it was tiresome.
30b. They stopped at many stations as they travelled in the packed train and it was tiresome.
30c. The young couple played cards together while on the packed train and it was relaxing.
30d. The elderly lady was frightened when she saw the packed train and it was sad.

31a. Jumping on the lily-pads in the pond, were lots of little green frogs and they looked cute.
31b. After hearing croaking noises, the kids saw lots of little green frogs and they looked cute.
31c. In the advert for the nature program, there were lots of little green frogs and they looked cute.
31d. In the children's television program there were lots of little green frogs and they looked cute.

32a. Fred was seen playing in the garden through the kitchen window and looked very cold.
32b. The mother shouted at her children from the kitchen window and looked very angry.
32c. The nosey teenager was standing alone by the kitchen window and looked very angry.
32d. Tom was speaking on the phone beside the kitchen window and looked very angry.

33a. Afraid of creepy-crawlies, Kim screamed when she saw a hairy spider crawling along the bath.
33b. When the kitten went to drink some milk, it noticed a hairy spider crawling along the floor.
33c. The little girl was absolutely terrified when she saw a hairy spider crawling along the bath.
33d. At the cinema, the couple watched a film which showed a hairy spider crawling along a body.

34a. In the zoo cage, swinging by its tail, was a little brown monkey and it looked cute.
34b. At the zoo, the young boy threw a banana to the little brown monkey and it ate it all.
34c. At the zoo, Ryan's favourite animal was the little brown monkey and he wanted it.
34d. Ryan bought himself a book which was about a little brown monkey and it wasn't cheap.

35a. The lovely wedding cake was cut using a long silver knife so that guests could have a piece.
35b. In the film, the man cut the noose with a long silver knife so that the prisoner could go free.
35c. Agnes was careful about where she laid the long silver knife so that her child would be safe.
35d. During her shopping trip, the lady bought a long silver knife so that she could cut cakes easily.

36a. Due to weight restrictions, lorries could only cross the narrow bridge very slowly.
36b. The only way to drive out of the city was to cross the narrow bridge very slowly.

36c. The group of foreign hitch-hikers travelled across the narrow bridge very slowly.

36d. The amazing artist painted a beautiful picture of the narrow bridge very slowly.

37a. The teenage boys played a game of poker using the deck of fancy cards they had bought.
37b. During games day, the school pupils played with the pack of fancy cards they had won.
37c. At Christmas, the couple were pleased with the amount of fancy cards they had received.
37d. The teenage twins were over the moon with the amount of fancy cards they had received.

38a. Fred couldn’t wait to put the saddle on and ride the tall black horse as it was a real beauty.
38b.The little girl was terrified of feeding the tall black horse as it looked intimidating.
38c. At the market, the rich farmer purchased the tall black horse as it was a real beauty.
38d.The little girls were absolutely terrified of the tall black horse as it looked intimidating.

39a. At the police station, the criminal got legal advice from his clever lawyer and felt happier.
39b. Hoping to get compensation, Ben sought advice from his clever lawyer and felt happier.
39c. Before selling his house, Douglas sought advice from his clever lawyer and felt happier.
39d. Unsure of what to do next, Henry sought advice from his clever lawyer and felt happier.

40a. Lisa put on her make-up and dried her hair in front of the round mirror in her bedroom.
40b. Jennifer practised her new dance moves in front of the round mirror in her bedroom.
40c. The naughty toddler put bright red lip-stick all over the round mirror in her bedroom.
40d. Jennifer searched all the cupboards but couldn’t find the round mirror in her bedroom.

41a. After he had put out the flames and rescued the baby, the brave fireman received a lot of praise.
41b. After he had rescued a cat from a really tall tree, the brave fireman received a lot of praise.
41c. After putting some cream on the burns victim, the brave fireman received a lot of praise.
41d. After his name appeared in the local newspaper, the brave fireman received a lot of praise.

42a. After killing many rebel fighters in the war, the brave soldier decided that he wanted to go home.
42b. After being shot in the arm by a gunman, the brave soldier decided that he wanted to go home.
42c. Everybody thought that he was the best, but the brave soldier decided that he wanted to go home.
42d. The lady really wanted to see her family, but the brave soldier decided to take her to hospital.

43a. Lizzy took some really nice photographs using the fancy camera she got at Christmas.
43b. As it was dirty, Elizabeth cleaned the lens of the fancy camera she got at Christmas.
43c. Elizabeth edited all of the photographs using the fancy camera she got at Christmas.
43d. Elizabeth’s favourite possession was definitely the fancy camera she got at Christmas.

44a. After having measles, Sam’s face was still covered with the nasty spots but she felt fine.
44b. Looking in the mirror, Samantha saw that she still had the nasty spots but she didn’t care.
44c. All of Claire’s face and body were still covered with the nasty spots but she didn’t care.
44d. Pam’s friend tried everything she could to get rid of the nasty spots but she didn’t manage.

45a. The animals could be seen grazing on the lovely green grass in the country.

45b. Many flowers were growing amongst the lovely green grass in the country.

45c. The young couple often sat together on the lovely green grass in the country.

45d. The couple were absolutely amazed by the lovely green grass in the country.

46a. At lunch, Emma gave her friend some segments of the little orange she had bought.
46b. After she had peeled it, Catherine noticed seeds in the little orange she had bought.
46c. During her lunch break, Emma peeled and ate all of the little orange she had bought.
46d. Since she was ill, Emma gave her friend flowers and the little orange she had bought.

47a. Kim had a burst pipe in her bathroom and had to call the local plumber but he was very busy.
47b. Catherine's radiator wasn't going on so she called the local plumber but he was very busy.
47c. Gary wasn't sure which pipes to buy, so he called the local plumber but he was very busy.
47d. Gary was surprised to hear that Alissa was dating the local plumber but he was quite happy.

48a. As her hands were cold, Kim put on her pair of pink woolly gloves and then felt warmer.
48b. As it was cold, Ann-Marie put on her pair of pink woolly gloves and then felt warmer.
48c. As it was cold outside, Ann-Marie put on her pink woolly gloves and then felt warmer.
48d. Ann-Marie searched her entire house for the pink woolly gloves and then found them.

APPENDIX F

Instructions for cloze task employed in Experiments 3 (as well as an example sentence fragment):

Please continue the sentence with the first word that comes into your mind. It's important not to spend a lot of time thinking about it – just put the very first word you think appropriate. It should only take 10-15 minutes to complete all of the sentences.

1. At the river, Karen heard quacking and saw a pair of cute brown ——————

APPENDIX G

Participant information sheet for Eye-tracking Experiment 3:

PARTICIPANT INFORMATION SHEET

The role of predictability effects in eye movement control during reading.

You are being asked to take part in an eye movement experiment which is being carried out as part of my PhD. The research is being supervised by Professor Alan Kennedy and Dr. Wayne Murray, both of this psychology department.

The study is an investigation into how predictable and unpredictable words are processed during normal reading. This will be investigated by tracking your eye movements as you read sentences on a computer screen. This research is beneficial to those in the field of eye movement control in reading.

Your participation in this study is voluntary and will take approximately 30-40 minutes of your time. The task is not at all stressful and there are no known risks for you in this study however you may decide to discontinue the experiment at any time without explanation. In return for your participation you will receive course credit.

The data we collect do not contain any personal information about you and no-one will link the data you provided to your identity and name.

The instructions for the experiment are as follows:

When this experiment begins, it will first be necessary to calibrate the eye tracker. Therefore, the first thing you will see will be a set of ‘calibration markers’. These are numbers on the screen which you will be asked to look at in turn. You should simply follow my instructions at this point.

Following the calibration procedure you will be asked to read a number of sentences presented on the screen in front of you. First, a fixation mark will appear on the screen. When you look at this, a sentence will be displayed. When you have finished reading the sentence, press the button on your right-hand side. The words ‘Press button’ will then appear on the screen and you should press the right-hand button again. Occasionally following a sentence a question will be displayed instead of the ‘Press button’ instruction. Answer the question by pressing either the right-hand button for “yes” or the left-hand button for “no” responses.

The procedure is thus:

- A fixation mark appears on the screen
- Look at the fixation mark
- A sentence appears on the display
- You read the sentence
- You press the right-hand button
- The ‘Press button’ instruction will appear on the screen
- You press the right-hand button
- On some occasions instead of the ‘Press button’ instruction, a question will follow the sentence
- You answer the question using the right button for ‘yes’ and the left for ‘no’
- A fixation mark appears. And so on…

If you get an answer wrong, you will hear a buzzer, but please note that this experiment is not a test of your reading ability or your intelligence. You will be given plenty of practice, providing an opportunity to familiarise yourself with the task.

Every now and then it will be necessary to re-calibrate the eye tracker. Re-calibration will be similar to the calibration procedure carried out at the beginning of the experiment. Simply follow my instructions when we reach this point.

It is very important that you keep you head **absolutely still** while the data are being collected. In particular, do not try to speak, even if you happen to get a question wrong. If you need to take a short break, the best time to do this is just before the calibration procedure. I will give you a rest break now and then, in any case.

If you have any questions or queries please raise them now. I will be glad to answer any questions about this study at any time, you can contact me by e-mail at S.S.Paul@dundee.ac.uk.

Shirley Paul, PhD student
Psychology Department
University of Dundee
DD1 4HN

The University Non-Clinical Research Ethics Committee of the University of Dundee has reviewed and approved this research study.

APPENDIX H

Participant information sheet for Eye-tracking Experiments 4 and 5:

PARTICIPANT INFORMATION SHEET

The role of predictability effects in eye movement control during reading.

You are being asked to take part in an eye movement experiment which is being carried out as part of my PhD. The research is being supervised by Professor Alan Kennedy and Dr. Wayne Murray, both of this psychology department.

The study is an investigation into how predictable and unpredictable words are processed during normal reading. This will be investigated by tracking your eye movements as you read sentences on a computer screen. This research is beneficial to those in the field of eye movement control in reading.

You participation in this study is voluntary and will take approximately 45 minutes of your time. The task is not at all stressful and there are no known risks for you in this study however you may decide to discontinue the experiment at any time without explanation. In return for your participation you will receive course credit or a payment of £5.

The data we collect do not contain any personal information about you and no-one will link the data you provided to your identity and name.

The instructions for the experiment are as follows:

When this experiment begins, it will first be necessary to calibrate the eye tracker. Therefore, the first thing you will see will be a set of 'calibration markers'. These are numbers on the screen which you will be asked to look at in turn. You should simply follow my instructions at this point.

Following the calibration procedure you will be asked to read a number of sentences presented on the screen in front of you. First, a fixation mark will appear on the screen. When you look at this, a sentence will be displayed. When you have finished reading the sentence, press the button on your right-hand side. The words 'Press button' will then appear on the screen and you should press the right-hand button again. Occasionally following a sentence a question will be displayed instead of the 'Press button' instruction. Answer the question by pressing either the right-hand button for "yes" or the left-hand button for "no" responses.

The procedure is thus:

- A fixation mark appears on the screen
- Look at the fixation mark
- A sentence appears on the display
- You read the sentence
- You press the right-hand button
- The ‘Press button’ instruction will appear on the screen
- You press the right-hand button
- On some occasions instead of the ‘Press button’ instruction, a question will follow the sentence
- You answer the question using the right button for ‘yes’ and the left for ‘no’
- A fixation mark appears. And so on…

If you get an answer wrong, you will hear a buzzer, but please note that this experiment is not a test of your reading ability or your intelligence. You will be given plenty of practice, providing an opportunity to familiarise yourself with the task.

Every now and then it will be necessary to re-calibrate the eye tracker. Re-calibration will be similar to the calibration procedure carried out at the beginning of the experiment. Simply follow my instructions when we reach this point.

It is very important that you keep you head **absolutely still** while the data are being collected. In particular, do not try to speak, even if you happen to get a question wrong. If you need to take a short break, the best time to do this is just before the calibration procedure. I will give you a rest break now and then, in any case.

If you have any questions or queries please raise them now. I will be glad to answer any questions about this study at any time, you can contact me by e-mail at S.S.Paul@dundee.ac.uk.

Shirley Paul, PhD student
Psychology Department
University of Dundee
DD1 4HN

The University Non-Clinical Research Ethics Committee of the University of Dundee has reviewed and approved this research study.

APPENDIX I

Table of correlations of independent variables employed in *lmer* analyses for zone 3 (Experiment 4).

	Predictability	**Preview Type**	**Plausibility**
Predictability			
Preview Type	0.58		
Plausibility	-0.21	-0.12	
Predictability by Preview Type	-0.71	-0.84	0.11

APPENDIX J

Table of correlations of independent variables employed in *lmer* analyses for zone 4 (Experiment 4).

	Skipping Rate (zone 3)	**Predictability**	**Preview Type**
Skipping Rate (zone 3)			
Predictability	0.04		
Preview Type	0.02	0.01	
Plausibility	0.02	-0.25	-0.01

APPENDIX K

Experimental sentence frames, target-previews and target words employed in Eye-tracking Experiment 5. The target-previews are italicized and separated by back-slashes and are either more or less predictable depending upon the preceding sentence context, or are non-predictable. The target words are under-lined and a, b, c and d refer to high, moderately-high, low-predictable and unpredictable sentence frames respectively:

1a. At the river, Karen heard quacking and saw a pair of cute brown *ducks/geese* geese swimming along together.
1b. The girls noticed some beautiful swans and a pair of cute brown *ducks/geese* geese swimming along together.
1c. While walking past the river, Amy saw a pair of cute brown *ducks/geese* geese swimming along together.
1d. While taking in the views, the girls noticed a pair of cute brown *ducks/geese* geese swimming along together.

2a. Although scared of being eaten alive, the diver swam by lots of giant *sharks/corals* corals and was intrigued.
2b. He knew they were dangerous, but the diver swam by lots of giant *sharks/corals* corals and was intrigued.
2c. In the warm Australian waters, the young diver saw lots of giant *sharks/corals* corals and was intrigued.
2d. While on an exotic holiday with his wife, Gordon saw lots of giant *sharks/corals* corals and was intrigued.

3a. In the children's story, the evil witch cast a lot of magic *spells/charms* charms and everyone was afraid.
3b. While in her attic, Judy found a book full of magic *spells/charms* charms and everyone was curious.
3c. The teenager attempted to carry out a lot of magic *spells/charms* charms and everyone was curious.
3d. The elderly woman taught her grandson a lot of magic *spells/charms* charms and everyone was curious.

4a. The girl bought her mother a bouquet of pink and purple *flowers/violets* violets for her new vase.
4b. Paula was kind, she took her friend some pink and purple *flowers/violets* violets for her bedside.
4c. Patricia bought most of the beautiful pink and purple *flowers/violets* violets for her new vase.
4d. The young lady couldn't wait to buy pink and purple *flowers/violets* violets for her new vase.

5a. In the garden, Jill fed carrots and lettuce to her fluffy brown *rabbit/ferret* ferret before she went to school.
5b. The young teenager went outside to feed her fluffy brown *rabbit/ferret* ferret before she went to school.
5c. Jill kept lots of animals, her favourite was her fluffy brown *rabbit/ferret* ferret before she got a cat.
5d. At the zoo, Rachel's favourite animal was the fluffy brown *rabbit/ferret* ferret before she saw the tigers.

6a. Evelyn spent hours reading the entries in her secret *diary/notes* notes and then went to bed.
6b. Evelyn spent hours and hours looking for her secret *diary/notes* notes and then went to bed.
6c. Evelyn would write for hours and hours in her secret *diary/notes* notes and then go to bed.
6d. Karen hadn't told any of her friends about her secret *diary/notes* notes and then they found out.

7a. Liz was cutting the hedges and watering the plants in the pretty *garden/estate* estate behind her house.
7b. Catriona's friend could be seen watering the plants in the pretty *garden/estate* estate behind her house.
7c. The elderly lady could be seen bird-watching in the pretty *garden/estate* estate behind her house.
7d. Catriona painted an absolutely wonderful picture of the pretty *garden/estate* estate behind her house.

8a. In the story, the princess was locked in a tower inside the stone *castle/palace* palace so no-one could find her.
8b. A huge drawbridge was built at the entrance of the stone *castle/palace* palace so no-one could enter.
8c. The knight kept his swords hidden in a room inside the stone *castle/palace* palace so no-one could find them.
8d. In the story, the children hid in a small room inside the stone *castle/palace* palace so no-one could find them.

9a. At Halloween, Ian used a white sheet to dress up as a scary *ghost/demon* demon and everyone laughed.
9b. At Halloween, Suzanne always liked to dress up as a scary *ghost/demon* demon and everyone laughed.
9c. In the movie, the group of teenagers were chased by a scary *ghost/demon* demon and everyone was scared.
9d. In the art gallery, there was a wonderful painting of a scary *ghost/demon* demon and everyone wanted it.

10a. Everyone laughed when the waitress dropped the dinner *plates/tables* tables she had been carrying.
10b. Kimberley saw a set of cups which matched the dinner *plates/tables* tables she had recently bought.
10c. Jenny served her friends a delicious meal on the dinner *plates/tables* tables she had recently bought.
10d. Jennifer's friend Rachel absolutely loved the dinner *plates/tables* tables she had recently bought.

11a. The soldier had his breakfast and did up the laces on his shiny *boots/shoes* shoes then was ready to go.
11b. The soldier put on his uniform and tied the laces on his shiny *boots/shoes* shoes then was ready to go.
11c. Upon waking, the soldier had his breakfast and put on his shiny *boots*/*shoes* shoes then was ready to go.
11d. William picked up his heavy back-pack and found his shiny *boots*/*shoes* shoes then was ready to go.

12a. At the party, Alf thought that Rita was wearing a very pretty *dress/frock* frock and looked lovely.
12b. It wasn't white, but the bride was still wearing a very pretty *dress/frock* frock and looked lovely.
12c. Samantha's friend had spent a lot of money on a very pretty *dress/frock* frock and looked lovely.
12d. Samantha accidentally spilled a glass of milk on a very pretty *dress/frock* frock and looked embarrassed.

13a. They looked for sea-shells and built sand-castles on the sunny *beach/shore* shore and were very happy.
13b. The young couple liked to walk bare-foot along the sunny *beach/shore* shore and were very happy.
13c. The kids loved the summer as they got to play on the sunny *beach/shore* shore and were very happy.
13d. The two artists painted some lovely pictures of the sunny *beach/shore* shore and were very happy.

14a. The tourists and locals thought that the artefacts inside the lovely *museum/studio* studio were very fascinating.
14b. The artefacts and relics that had been preserved inside the lovely *museum/studio* studio were very fascinating.
14c. The children thought that the paintings and statues inside the lovely *museum/studio* studio were very fascinating.
14d. Although the building was ancient, the paintings inside the lovely *museum/studio* studio were very popular.

15a. Caroline fed both her pets then groomed them using the round *brush/dryer* dryer she had recently bought.
15b. The hair-dresser cut Kim's hair then styled it using the round *brush/ dryer* dryer she had recently bought.
15c. Carol put on her clothes then tidied her hair using the round *brush/dryer* dryer she had recently bought.
15d. The bad-tempered little girl hit her big brother with the round *brush/dryer* dryer she had recently bought.

16a At the recycling centre, Ian accidentally smashed the glass *bottle/carafe* carafe and got into trouble.
16b. Little Jimmy drank all of the Irn-bru straight from the glass *bottle/carafe* carafe and got into trouble.
16c. While pouring juice, Kim accidentally smashed the glass *bottle/carafe* carafe and got into trouble.
16d. At lunch, Ian leaned over, accidentally smashed the glass *bottle/carafe* carafe and got into trouble.

17a. Liz wrote the address on the envelope and stuck on the festive *stamp/label* label before posting the card.
17b. Tracey sent her daughter to the Post Office to buy a festive *stamp/label* label before posting the card.
17c. At the shop, Tracey bought a card, envelope and a festive *stamp/label* label before posting her mail.
17d. At the local shop, Tracey bought pens, paper and a festive *stamp/label* label before posting her letters.

18a. In the forest, there were people chopping down the dying *trees/ferns* ferns and taking them away.
18b. In the far distance, people were chopping down the dying *trees/ferns* ferns and taking them away.
18c. The rowdy teenagers could be seen breaking up the dying *trees/ferns* ferns and taking them away.
18d. In the far distance, people were bringing down the dying *trees*/ferns ferns and taking them away.

19a. At Halloween, Ryan’s father carved a face into the large round *pumpkin/turnips* turnips and it looked scary.
19b. At the Halloween party, Martin played with the large round *pumpkin/turnips* turnips and it was fun.
19c. At Halloween, Ryan’s mother made soup using the large round *pumpkin/turnips* turnips and it was tasty.
19d. Martin’s friend was absolutely terrified of the large round *pumpkin/turnips* turnips and he began crying.

20a. Joseph looked at his wrist to check the time on the silver *watch/timer* timer he got at Christmas.
20b. During his break, Joseph checked the time on the silver *watch/timer* timer he got at Christmas.
20c. As it was too big, Joe got some links taken out of the silver *watch/timer* timer he got at Christmas.
20d. He searched his whole house, but Joe didn’t find the silver *watch/timer* timer he got at Christmas.

21a. Victoria’s friend thought that the best circus act was the funny *clown*/*woman* woman in the baggy trousers.
21b. Sally had been practising juggling as she was playing the funny *clown*/*woman* woman in the local circus.
21c. Sid needed to learn some jokes as he was playing the funny *clown/woman* woman in the local circus.
21d. Victoria was absolutely desperate to look like the funny *clown/woman* woman in the baggy trousers.

22a. After her shower, Rebecca dried herself using the clean *towel/cloth* cloth from the rack.
22b. While cleaning the bathroom, the maid folded the clean *towel/cloth* cloth from the rack.
22c. Unsure if it had been used, the maid picked up the clean *towel/cloth* cloth from the rack.
22d. Rebecca’s dog got muddy paw-prints all over the clean *towel/cloth* cloth from the rack.

23a. The whistling noise in the kitchen came from the green *kettle/teapot* teapot that everyone shared.
23b. Amanda made herself a cup of coffee using the green *kettle/teapot* teapot that everyone shared.
23c. Amanda made herself a cup of soup using the green *kettle/teapot* teapot that everyone shared.
23d. Amanda went shopping and bought herself the green *kettle/teapot* teapot that everyone was looking at.

24a. At the office, David kept his juice cool in the mini silver *fridge/cooler* cooler he got for his birthday.
24b. At the office, David kept his juice inside the mini silver *fridge/cooler* cooler he got for his birthday.
24c. At the office, David kept his lunch inside the mini silver *fridge/cooler* cooler he got for his birthday.
24d. Ted fixed the fan which had broken inside the mini silver *fridge/cooler* cooler he got for his birthday.

25a. After listening to the boy's heart with the stethoscope, the junior *doctor/intern* intern gave the bad news.
25b. After she had taken some blood and urine samples, the junior *doctor/intern* intern gave the lady advice.
25c. After listening to all of the patient's problems, the junior *doctor/intern* intern gave the bad news.
25d. After having a romantic dinner in a fancy restaurant, the junior *doctor/intern* intern gave the lady flowers.

26a. At his friend's birthday party, Edward burst the giant *balloon/present* present and then got upset.
26b. At the show, the entertainer made a dog out of the giant *balloon/present* present and then burst it.
26c. At the party, the boy cried when he let go of the giant *balloon/present* present and then felt silly.
26d. The little boy was fascinated when he saw the giant *balloon/present* present and then the clown.

27a. The vocal coach knew the young girl would be a lovely *singer/person* person when she grew up.
27b. Cassandra had a great musical career as she was a lovely *singer/person* person when she tried.
27c. Cassandra made it into the pop band as she was a lovely *singer/person* person when she tried.
27d. Everybody thought that young Cassandra was a lovely *singer/person* person when she tried.

28a. After hitting a hole in one twice in a row, the amazing *golfer/putter* putter won the game.
28b. His last ball initially went past the hole, but the amazing *golfer/putter* putter won the game.
28c. The lucky tee seemed to work because the amazing *golfer/putter* putter won the game.
28d. Even though he had drunk a lot of alcohol, the amazing *golfer/*putter won the game.

29a. In the morning, Andy neatly tied the stripy tie on top of the brown *shirt/tunic* tunic he wore to work.
29b. As Tim was attending an interview, he dried and ironed the brown *shirt/tunic* tunic he wore to work.
29c. Tim looked for the pair of trousers which matched the brown *shirt/tunic* tunic he wore to work.
29d. Craig looked everywhere in the house but couldn't find the brown *shirt/tunic* tunic he wore to work.

30a. The couple travelled across the railway bridge in the packed *train/wagon* wagon and it was tiresome.
30b. They stopped at many stations as they travelled in the packed *train/wagon* wagon and it was tiresome.
30c. The young couple played cards together while on the packed *train/wagon* wagon and it was relaxing.
30d. The elderly lady was frightened when she saw the packed *train/wagon* wagon and it was sad.

31a. Jumping on the lily-pads in the pond, were lots of little green *frogs/newts* newts and they looked cute.
31b. After hearing croaking noises, the kids saw lots of little green *frogs/newts* newts and they looked cute.
31c. In the advert for the nature program, there were lots of little green *frogs/newts* newts and they looked cute.
31d. In the children's television program there were lots of little green *frogs/newts* newts and they looked cute.

32a. Fred was seen playing in the garden through the kitchen *window/screen* screen and looked very cold.
32b. The mother shouted at her children from the kitchen *window/screen* screen and looked very angry.
32c. The nosey teenager was standing alone by the kitchen *window/screen* screen and looked very angry.
32d. Tom was speaking on the phone beside the kitchen *window/screen* screen and looked very angry.

33a. Afraid of creepy-crawlies, Kim screamed when she saw a hairy *spider/earwig* earwig crawling along the bath.
33b. When the kitten went to drink some milk, it noticed a hairy *spider/earwig* earwig crawling along the floor.
33c. The little girl was absolutely terrified when she saw a hairy *spider/earwig* earwig crawling along the bath.
33d. At the cinema, the couple watched a film which showed a hairy *spider/earwig* earwig crawling along a body.

34a. In the zoo cage, swinging by its tail, was a little brown *monkey/baboon* baboon and it looked cute.
34b. At the zoo, the young boy threw a banana to the little brown *monkey/baboon* baboon and it ate it all.
34c. At the zoo, Ryan's favourite animal was the little brown *monkey/baboon* baboon and he wanted it.
34d. Ryan bought himself a book which was about a little brown *monkey/baboon* baboon and it wasn't cheap.

35a. The lovely wedding cake was cut using a long silver *knife/blade* blade so that guests could have a piece.
35b. In the film, the man cut the noose with a long silver *knife/blade* blade so that the prisoner could go free.
35c. Agnes was careful about where she laid the long silver *knife/blade* blade so that her child would be safe.
35d. During her shopping trip, the lady bought a long silver *knife/blade* blade so that she could cut cakes easily.

36a. Due to weight restrictions, lorries could only cross the narrow *bridge/street* street very slowly.
36b. The only way to drive out of the city was to cross the narrow *bridge/street* street very
36c. The group of foreign hitch-hikers travelled across the narrow *bridge/street* street very slowly.
36d. The amazing artist painted a beautiful picture of the narrow *bridge/street* street very slowly.

37a. In the Western film, the horse, gun and lasso were stolen by a fierce *cowboy/person* person who was feared.
37b. In the old Western film, the friendly Indian was killed by a fierce *cowboy/person* person who was feared.
37c. Dean watched an old Western film which was about a fierce *cowboy/person* person who was feared.
37d. Dean and Frank watched an old film which was about a fierce *cowboy/person* person who was feared.

38a. Fred couldn't wait to put the saddle on and ride the tall black *horse/steed* steed as it was a real beauty.
38b.The little girl was terrified of feeding the tall black *horse/steed* steed as it looked intimidating.
38c. At the market, the rich farmer purchased the tall black *horse/steed* steed as it was a real beauty.
38d.The little girls were absolutely terrified of the tall black *horse/steed* steed as it looked intimidating.

39a. At the police station, the criminal got legal advice from his clever *lawyer/sister* sister and felt happier.
39b. Hoping to get compensation, Ben sought advice from his clever *lawyer/sister* sister and felt happier.
39c. Before selling his house, Douglas sought advice from his clever *lawyer*/*sister* sister and felt happier.
39d. Unsure of what to do next, Henry sought advice from his clever *lawyer/sister* sister and felt happier.

40a. Lisa put on her make-up and dried her hair in front of the round *mirror/screen* screen in her bedroom.
40b. Jennifer practised her new dance moves in front of the round *mirror/screen* screen in her bedroom.
40c. The naughty toddler put bright red lip-stick all over the round *mirror/screen* screen in her bedroom.
40d. Jennifer searched all the cupboards but couldn't find the round *mirror/screen* screen in her bedroom.

41a. After he had put out the flames and rescued the baby, the brave *fireman/soldier* soldier received a lot of praise.
41b. After he had rescued a cat from a really tall tree, the brave *fireman/soldier* soldier received a lot of praise.
41c. After putting some cream on the burns victim, the brave *fireman/soldier* soldier received a lot of praise.
41d. After his name appeared in the local newspaper, the brave *fireman/soldier* soldier received a lot of praise.

42a. After killing many rebel fighters in the war, the brave *soldier*/*warrior* warrior decided that he wanted to go home.
42b. After being shot in the arm by a gunman, the brave *soldier/warrior* warrior decided that he wanted to go home.
42c. Everybody thought that he was the best, but the brave *soldier/warrior* warrior decided that he wanted to go home.
42d. The lady really wanted to see her family, but the brave *soldier/warrior* warrior decided to take her to hospital.

43a. Lizzy took some really nice photographs using the fancy *camera/mobile* mobile she got at Christmas.
43b. As it was dirty, Elizabeth cleaned the lens of the fancy *camera/mobile* mobile she got at Christmas.
43c. Elizabeth edited all of the photographs using the fancy *camera/mobile* mobile she got at Christmas.
43d. Elizabeth's favourite possession was definitely the fancy *camera/mobile* mobile she got at Christmas.

44a. After having measles, Sam's face was still covered with the nasty *spots/hives* hives but she felt fine.
44b. Looking in the mirror, Samantha saw that she still had the nasty *spots/hives* hives but she didn't care.
44c. All of Claire's face and body were still covered with the nasty *spots/hives* hives but she didn't care.
44d. Pam's friend tried everything she could to get rid of the nasty *spots/hives* hives but she didn't manage.

45a. The animals could be seen grazing on the lovely green *grass/lawns* lawns in the country.
45b. Many flowers were growing amongst the lovely green *grass/lawns* lawns in the country.
45c. The young couple often sat together on the lovely green *grass/lawns* lawns in the country.
45d. The couple were absolutely amazed by the lovely green *grass/lawns* lawns in the country.

46a. At lunch, Emma gave her friend some segments of the little *orange/papaya* papaya she had bought.
46b. After she had peeled it, Catherine noticed seeds in the little *orange/papaya* papaya she had bought.
46c. During her lunch break, Emma peeled and ate all of the little *orange/papaya* papaya she had bought.
46d. Since she was ill, Emma gave her friend flowers and the little *orange/papaya* papaya she had bought.

47a. Kim had a burst pipe in her bathroom and had to call the local *plumber/janitor* janitor but he was very busy.
47b. Catherine's radiator wasn't going on so she called the local *plumber/janitor* janitor but he was very busy.
47c. Gary wasn't sure which pipes to buy, so he called the local *plumber/janitor* janitor but he was very busy.
47d. Gary was surprised to hear that Alissa was dating the local *plumber/janitor* janitor but he was quite happy.

48a. The new doors would be fitted very soon as the local *joiner/helper* helper was coming round later.
48b. Alan was asked for the door measurements as the local *joiner/helper* helper was coming round later.
48c. Alan hurriedly bought the wood he wanted as the local *joiner/helper* helper was coming round later.
48d. Alan ensured the house was clean and tidy as the local *joiner/helper* helper was coming round later.

APPENDIX L

Table of correlations of independent variables employed in *lmer* analyses for zone 3 (Experiment 5).

	Ctxt.Con.	**Prev-P.**	**Skipping Rate Z4**	**Plausibility**	**Prev-P by Skip Z4**
Ctxt. Con.					
Prev-P.	0.58				
Skipping Rate Z4	-0.01	0.14			
Plausibility	-0.17	0.00	-0.02		
Prev-P by Skip Z4	0.01	-0.19	-0.69	0.02	
Ctxt.Con.by Prev-P.	-0.70	-0.82	0.01	-0.00	-0.02

Note: Ctxt. Con. = Contextual Constraint. Prev-P. = Preview-Predictability.

APPENDIX M

Table of correlations of independent variables employed in *lmer* analyses for the final model for zone 4 (Experiment 5).

	Ctxt.Con.	**Preview Type**
Ctxt. Con.		
Preview Type	0.00	
Plausibility	-0.24	0.00

Note: Ctxt. Con. = Contextual Constraint.